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DIPLOMA THESIS

Light oil phase textile sorbent into remediation wells

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Abstract

There is a great need to keep environment safe from huge threat of contaminants that are spreading at high speed above and below the ground. The main reason evolves from the dramatically increase in the usage of chemicals in many sectors and machinery where oils and fuels are demanding. This paper is based on studying the efficiency of a designed textile sorbent from nonwoven material (made from polypropylene fibers) when it is applied in light oil phase into remediation wells. The following tests were carried: capillary action tests included plain strips, tubular sorbent in oil and weight test (oil only). The absorption and capillary action include test in measuring cylinder (oil on water) and this is last test which reflects nature situation. The trip tests categorized polypropylene materials made of different nonwoven technologies and different properties according to their efficiency in absorbing oil.

Two different types of sorbents were compared, completely hydrophobic ECT and ECT U that possesses both hydrophobic and hydrophilic properties. Among each of these sorbents comparison was also done, heavy (high density) against light (low density) samples. The main experimental parameters are the following: time taken for sample to reach maximum capacity, height travelled by oil during capillary action and gram oil per gram textile ratio. It was also interesting to check whether the sorbent sink at the end of experiment. The experimental results showed that ECT and ECT U heavy samples have high oil absorption capacity compared to light samples due to their better retention time. ECT U sorbents have better affinity to oil than to water. In nature simulating tests (test in measuring cylinder) absorption rate is very higher because 200ml oil is absorbed within 5-7 minutes and 396.8 ml within one hour for cylinder with 50mm diameter and 250mm long. The sorbents will not sink if used in nature.

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List of abbreviations

SO	Specific content of oil g/g [-]
MDT	Mass of dry textiles [g]
MDCS	Mass of dry cut strips [g]
ACS	Area of cut strips [m^2]
MOS	Mass of oil absorbed by sorbent [g]
MS	Mass on scale [g]
AOR	Amount of oil left in cylinder after sample removed [ml]
TOA	Total amount of oil added [ml]
VOA	Volume of oil absorbed [ml]
W_c	Wicking coefficient [$cm/s^{1/2}$]
H	Liquid front position or wicking length [cm]
r_c	Effective hydraulic radius of the capillaries [cm]
η	Viscosity of the liquid [cm^2/s]
θ	Apparent contact angle of the moving front [-]
γ	Surface tension of liquid [cm^{-1}]
t	Time [s]
S24	Oil-water standard test 24 hours
C24	Oil-water compare test 24 hours
L13	Oil-water long test 13 days
L7	Start water-oil long test 7 days

Key words:

Remediation wells, Textile sorbents, Light oil phase, Wicking, Absorption

Chapter 1

1. Introduction

Sorbent materials are used to remove light organic compounds (hydrocarbons) from water especially fuels such as petroleum, diesel, paraffin and heavy fuel oil. Waste oil is generated from mechanical servicing, leaking vehicles and mining machinery. In studies of contaminant hydrogeology it was observed that hydrocarbons typically enter the groundwater environment from leaking storage tanks or pipelines, or spillages [2]. Nonwovens materials have been used frequently for this kind of work whereby fabrics are made of hydrophobic fibers such polypropylene. The hydrophobicity and oleophilicity are the most important properties of a sorbent to be considered in light organic compounds because the material should absorb or adsorb only hydrocarbons not water. There are three most important parameters for nonwoven sorbents: liquid absorbency time, liquid absorbency capacity and the liquid wicking rate.

There is a great need to keep environment and ecosystem safe from the huge threat of light and heavy organic contaminants such as oils in water. The sorbent materials are very useful in cleaning up oil contaminated water because they have a significant capacity for oil recovery from the surface of water, minimum harmful effects on ecosystems, and a low price [1]. Sorbents recover oil from water by either adsorption or absorption mechanisms. Adsorption is the distribution of the adsorbate over the surface of the adsorbent, while absorption is the distribution of the absorbate throughout the body of the absorbent [1]. Sorbent materials are able to sorb hydrocarbons easy simple because hydrocarbons such as fuels float in water. Chlorinated hydrocarbons cannot be easy absorbed compared to fuels because they tend to sink to the bottom of aquifers.

During our experimentation three tests will be used following Association of Nonwoven Fabrics Industry (INDA and European Disposables and Nonwovens Association (EDANA) standard test methods. The basic plane (strips) nonwoven material will be tested to see their ability to sorb oil from water and the pleated nonwoven material that is folded into cylindrical shape will be also tested because cylindrical shape sorbent is used in drilled remediation wells. The first test will be carried with oil only and the second one will be with oil on the water surface because the sorbents behave differently when tested in different environments. The main aim of this research is to test basic sorbent materials especially their ability to sorb oil from underground contaminated water.

This will be done by monitoring the parameters such as liquid absorbency time, liquid absorbency capacity and the liquid wicking rate. These are explained in details on chapter 2.4. The models of sorbents (cylindrical shape type) will be design and study their effectiveness when used into remediation wells. The designed cylindrical sorbents are 50mm in diameter (for laboratory tests satisfaction) which is smaller than that in remediation wells in nature (120mm diameter approximately). It is vital to understand that the thickness of oil on the surface of water in nature is about 3-30mm according to Aqua-test firm doing remediation. The time required for keeping sorbent in wells needs to be studied as well. Before the experimental work literature review was made.

Chapter 2

2. Literature Review

2.1 Contamination of underground Water

Underground water is the most important source of water in people's life for rest of the world. "About half the population in the United States relies to some extent on groundwater as a source of drinking water, and still more use it to supply their factories with process water or their farms with irrigation water" (Mason) [3]. "A groundwater pollutant is any substance that, when it reaches an **aquifer,** makes the water unclean or otherwise unsuitable for a particular purpose. Sometimes the substance is a manufactured chemical, but just as often it might be microbial contamination. Contamination also can occur from naturally occurring mineral and metallic deposits in rock and soil" (Mason) [3]. For many years, people believed that the soil and **sediment** layers deposited above an aquifer acted as a natural filter that kept many unnatural pollutants from the surface from infiltrating down to groundwater. However, in 1970s people have realized that those soil layers often did not adequately protect aquifer. Scientists have realized that once an aquifer becomes polluted, it may become unusable for decades, and is often impossible to clean up quickly and inexpensively [3].

"Groundwater pollution is caused by human activities usually falls into one of two categories: point-source pollution and nonpoint-source pollution**. Point-source pollution** refers to contamination originating from a single tank, disposal site, or facility. Industrial waste disposal sites, accidental spills, leaking gasoline storage tanks, and dumps or landfills are examples of point sources. Chemicals used in agriculture, such as fertilizers, **pesticides** and **herbicides** are examples of **nonpoint-source pollution** because they are spread out across wide areas" (Mason) [3].

Groundwater pollution can be due to natural substances like such as inorganic metals. One of the known classes of groundwater contaminants includes petroleum-based fuels such as gasoline, diesel, petrol, motor oils, organic solvents and fats. Some other contaminants come from acids, alkalis, solvents and toxic liquids. Nationally, the U.S. Environmental Protection Agency (EPA) has recorded that there have been over 400,000 confirmed releases of petroleum-based fuels from leaking underground storage tanks [3].

Contaminants are sometimes divided according to their densities in comparison to the density of water. For example, components from gasoline (benzene) have less density than water so they float in water that makes it easy to remove them from water. However chlorinated (for example, perchloroethylene) compounds are heavier than water so they sink to the bottom of the aquifer makes it difficult to clean up water. Chlorine present in chlorinated solvents makes this class of compounds more toxic than fuels [3].

It is important to understand the behavior of contaminant in underground water. In studies of contaminant hydrogeology it has been observed that contaminants behaving differently within groundwater systems based on their physical or chemical nature. For instance hydrocarbons may be hydrophobic and may be immiscible or insoluble in water, forming separate phases with water (non-aqueous phase liquids or NAPLs). Poorly soluble chemicals may form emulsions, while others may be taken partially into solution as dissolved phases dependent on their solubility. Chemicals which are less dense than water ('LNAPLs', e.g. hydrocarbons) tend to float on the water table, forming a distinct layer which represents a continuous source of dissolved phase contaminant due to groundwater underflow. Chemicals denser than water ('DNAPLs) tend to sink through the water column, and may pool at the base of aquifers upon lower permeability layers; these may also form continuous sources of dissolved contamination [2]. The good knowledge of different types of water contaminants leads to appropriate approach of water decontamination.

2.2 Decontamination of Water

Many methods and apparatus exist for decontaminating soil and ground water from compounds such as hydrocarbons and other organic and inorganic compounds. Ground water contamination can diffuse in a large area which makes complications for identification and investigation. Before decontamination is carried out, it is important to do hydro-geological assessment and pollution degree of different sections of contaminated area is defined. The most common way of removing a full range of contaminants (including metals, volatile organic chemicals, and pesticides) from an aquifer is by capturing the pollution with groundwater extraction wells. After it has been removed from the aquifer, the contaminated water is treated above ground, and the resulting clean water is discharged back into the ground or to a river.

Pump-and-treat, as this cleanup technology is known, can take a long time, but can be successful at removing the majority of contamination from an aquifer [3].

Another way of removing volatile chemicals from groundwater is by using a process known as air sparging. Small-diameter wells are used to pump air into the aquifer. As the air moves through the aquifer, it evaporates the volatile chemicals. The contaminated air that rises to the top of the aquifer is then collected using vapor extraction wells.

Bioremediation is a treatment process that uses naturally occurring microorganisms to break down some forms of contamination into less toxic or non-toxic substances. By adding nutrients or oxygen, this process can be enhanced and used to effectively clean up a contaminated aquifer. Because bioremediation relies mostly on nature, involves minimal construction or disturbance, and is comparatively inexpensive, it is becoming an increasingly popular cleanup option.

Some of the newest cleanup technologies use surfactants (similar to dishwashing detergent), oxidizing solutions, steam, or hot water to remove contaminants from aquifers. These technologies have been researched for a number of years, and are just now coming into widespread use. These and other innovative technologies are most often used to increase the effectiveness of a pump-and-treat cleanup [3].

Depending on the complexity of the aquifer and the types of contamination, some groundwater cannot be restored to a safe drinking quality. Under these circumstances, the only way to regain use of the aquifer is to treat the water at its point of use. For large water providers, this may mean installing costly treatment units consisting of special filters or evaporative towers called air strippers. Domestic well owners may need to install an expensive whole-house carbon filter or a reverse osmosis filter, depending on the type of contaminant [3].

Sorbents have significant capacity for oil recovery from the surface of water, minimum harmful effects on ecosystems, and a low price. Sorbents recover organic compounds either by adsorption or absorption mechanism. Adsorption is the distribution of adsorbate over the surface of the adsorbent, while absorption is the distribution of the absorbate throughout the body of the absorbent. Sorbent can change the oil from the liquid to a semisolid phase. Then, the oil will be easily recovered by the removal of the sorbent structure. Hydrophobicity and oleophilicity are the most important properties of a sorbent to be considered in oil spill cleanup [1]. Therefore, the most important fiber that has both of these requirements is polypropylene.

Other important factors are the retention over time, the recovery of oil from sorbents, the amount of oil sorbed per unit weight of sorbent, the reusability and the biodegradability of sorbents.

Bagasse and rice hull are other ways of removing oil from water but since they contain small particle sizes, it was difficult to collect and remove the wetted sorbents after they had been used. Therefore, these sorbents were wrapped into a net cloth made of hydrophobic material and then floated on the water surface. It is clear that the sorption capacity might be affected by the net cloth, but material, size and weight of the net cloth were maintained constant in all experiments, so that this effect was the same [1]. Second way includes dispersants which are generally liquid chemicals which accelerate the dispersion of the oil by reducing the surface tension between the oil and water when applied to the surface of the spilled area. These chemicals are usually toxic and release volatiles to the atmosphere and they are costly. Their application is limited through legislation considerations. In contrast to dispersants, herding agents (thickeners) can be added to an oil spill to thicken the oil. These agents increase the surface tension between the oil and water, thus reducing spreading of the spill and providing easier cleanup. Again, these chemicals are expensive and toxic. In addition, the thickened oil will sink sooner than oil which has not been treated [1]. Among many different ways of water decontamination textile sorbents made from polypropylene fibers is also applied in oil removal from water.

2.3 Types of oil sorbents generally

There are several types of oil sorbents and other kinds of oil cleanup from water surface, these include the following:

- Physical methods such as sorbents (Bagasse and rice hull, and polypropylene fibers), booms and skimmers.
- Chemical methods such as dispersion, in-situ burning and the use of solidifiers.
- Biological methods or bioremediation.

2.3.1 Textile materials for production of sorbents

The most important sorbent material is polypropylene. Polypropylene is a thermoplastic polymer of the chemical designation $[C_3H_6]_n$ (figure 2.1).

It is used in many different settings, both in industry and in consumer goods. It can be used both as a structural plastic and as a fiber.

Polypropylene is often used for food containers, particularly those that need to be dishwasher safe. The melting point of polypropylene is very high compared to many other plastics, at 320°F (160°C), which means that the hot water used when washing dishes will not cause polypropylene dishware to warp [5]. Polypropylene is hydrophobic therefore polypropylene does not get affected by moisture as its moisture absorption is very low but it is highly possible to modify it by treating the surface so that it become hydrophilic. The chemicals that are used to impart hydrophilicity to fibers are referred to as rewetters. These treatments increase the critical surface tension of the fiber making it more wettable. For hydrophobic fibers the treatment facilitates the movement and penetration of the liquid in the capillary channels. Many anionic and nonionic surfactants, antistats, flame retardants and softeners impart hydrophilicity [7]. The treating solution has Triethanolamine Dodecylbenzene Sulfonate (LAS) as the active ingredient. This treatment may use heated air (125° to 200° F) as a drying assist which renders the membrane to have a substantially instantaneous "wet-out" [14].

The surface on one side of a hydrophobic polypropylene membrane was modified with a gaseous plasma of 60 W discharge power in the presence of ammonia gas at 0.9 Torr pressure. Results of contact angle measurements indicate that one side of the hydrophobic membrane was modified; it became hydrophilic while the other side remained hydrophobic. Data from ESCA (electron spectroscopy for chemical analysis; X-ray photoelectron spectroscopy) and ATR-IR (attenuated total reflectance infrared) spectral analysis showed that the hydrophilicity was mainly derived from the amino groups on the modified surface [9]. Beside the surface treatment the chemicals can be added into a melted polymer during fiber making. This method is more permanent compared to surface treatment. It has got lowest cost because of its low density.

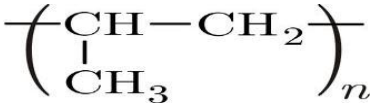


Figure 2.1: Structure of polypropylene [5]

Polypropylene remains unaffected by chemicals like alkaline substances, acids, de-greasing agents, electrolytic attacks, etc. However, its resistance towards aromatic or aliphatic hydrocarbons, chlorinated solvents and ultraviolet radiation is not very strong.

It is a non- poisonous material, it does not get stained very easily and it can retain its stiffness and flexibility at very high temperatures [5]. The good understanding of textile materials leads to appropriate choice of the technology that can be used to produce nonwovens materials.

2.4 Nonwovens and Technologies

Nonwovens fabrics are different than the conventional textile fabrics and paper. Nonwovens are not based on yarns and (with frequent exceptions) do not contain yarns. They are based on webs of individual fibers. Nonwovens include a wide variety of technologies and products. The products possess various structures, properties and end-uses. The definitions of the nonwovens most commonly used nowadays are those by the (INDA) and (EDANA). Nonwovens are a sheet, web, or bat of natural and/or man-made fibers or filaments, excluding paper, that have not been converted into yarns, and that are bonded to each other by any of several means, according to INDA which is similar to EDANA [4].

2.4.1 Melt Blown

Melt blown technology is suitable for processing of polypropylene into nonwovens. The basic technology to produce microfibers was first developed under U.S. government sponsorship in the early 1950s. Melt blowing (MB) is a process for producing fibrous webs or articles directly from thermoplastic polymers or resins using high-velocity air to attenuate the **filaments**. MB is a unique process because it is used almost exclusively to produce microfibers rather than fibers the size of normal textile fibers. MB microfibers generally have diameters in the range of 2 to 4 µm, although they may be as small as 0.1 µm and as large as 10 to 15 µm. Differences between MB nonwoven fabrics and other nonwoven fabrics, such as degree of softness, cover or opacity (not transparent), and porosity can generally be traced to differences in filament size [8].

The schematic of the process is shown MB in figure 2.2. A typical MB process consists of the following elements: extruder, metering pumps, die assembly, web formation, and winding.

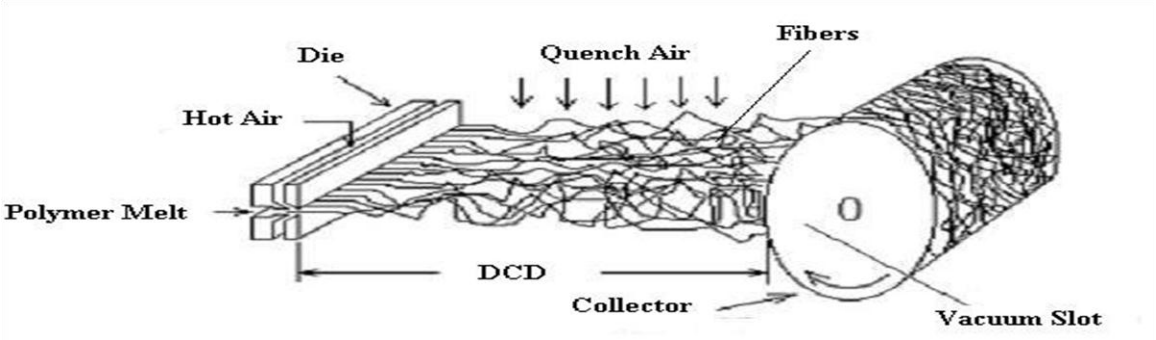


Figure 2.2: Schematic of MB process [7]

The extruder is one of the important elements in all polymer processing. It consists of a heated barrel with a rotating screw inside. Its main function is to melt the polymer pellets or granules and feed them to the next step or element. There are four different heaters in the extruder. The extruder is divided in to three different zones [7].

The **die assembly** is the most important element of the melt blown process. It has three distinct components: polymer-feed distribution, die nosepiece, and air manifolds [7].

The feed distribution is usually designed in such a way that the polymer distribution is less dependent on the shear properties of the polymer. This feature allows the melt blowing of widely different polymeric materials with one distribution system. The feed distribution balances both the flow and the residence time across the width of the die [7].

The polymer melt is extruded from these holes to form filament strands which are subsequently attenuated by hot air to form fine fibers. The air manifolds supply the high velocity hot air (also called as primary air) through the slots on the top and bottom sides of the die nosepiece. . The high velocity air is generated using an air compressor. Typical air temperatures range from 230°C to 360°C [7].

During **web formation**, as the hot air stream containing the microfibers progresses toward the collector screen, it draws in a large amount of surrounding air that cools and solidifies the molten fibers. The solidified fibers subsequently get laid randomly onto the collecting screen, forming a self-bonded nonwoven web. The fibers are generally laid randomly and also highly entangled.

The collector speed and the collector distance from the die nosepiece can be varied to produce a variety of melt-blown webs. Usually, a vacuum is applied to the inside of the collector screen to withdraw the hot air and enhance the fiber laying process. Thermal bonding is commonly used technique for bonding melt blown webs by area bonding or spot bonding, where by web and abrasion resistance are increased. Variables such as air temperature, polymer/die temperature, die to collector distance (DCD), collector speed, polymer throughput and air throughput. All of these affect the final properties of the nonwoven web [7]. The type of polymer or resin used in the meltblown will define the elasticity, softness, wetability, dyeability, chemical resistance. Polypropylene is easy to process in the melt-blown compared to other polymers such as polyethylene. Main applications of melt-blown webs are filtration, thermal insulation, oil absorption, etc, because fibers offer high surface and small pores [7].

2.4.2 SpunBond

Spunbond fabrics are produced by depositing extruded, spun filaments onto a collecting belt in a uniform random manner followed by bonding the fibers (figure 2.3). Bonding imparts strength and integrity to the web by applying heated rolls or hot needles to partially melt the polymer and fuse the fibers together. Since molecular orientation increases the melting point, fibers that are not highly drawn can be used as thermal binding fibers. Polyethylene or random ethylene-propylene copolymers are used as low melting bonding sites [7].

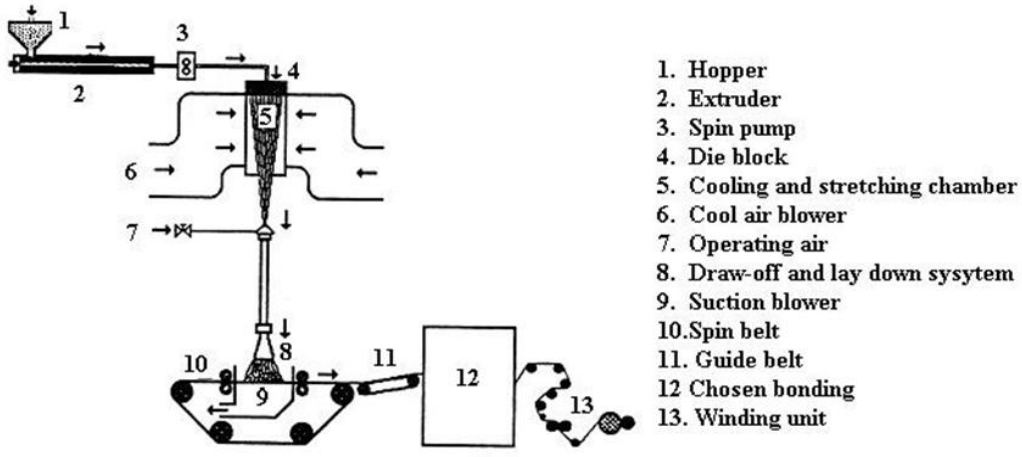


Figure 2.3: Schematic of spunbonding process [7]

The spinning process is similar to the production of continuous filament yarns and utilizes similar extruder conditions for a given polymer. Fibers are formed as the molten polymer exits the spinnerets and is quenched by cool air. The objective of the process is to produce a wide web and, therefore, many spinnerets are placed side by side to generate sufficient fibers across the total width. Before deposition on a moving belt, the output of a spinneret usually consists of a hundred or more individual filaments which must be attenuated to orient molecular chains within the fibers to increase fiber strength and decrease extensibility. Many methods can be used to bond the fibers in the spun web. Although most procedures were developed for nonwoven staple fibers, they have been successfully adapted for continuous filaments. These include mechanical needling, thermal bonding, and chemical bonding [7].

Spunbond filaments have a diameter that ranges between 1 and 50µm, typically 15-35µm [7]. Spunbonded webs offer a wide range of product characteristics ranging from very light and flexible structure to heavy and stiff structure. Generally the web is white with high opacity per unit area, high tear strength (for area bonded webs only), planar isotropic properties due to random lay-down of the fibers, good fray and crease resistance and high liquid retention capacity. Applications of spunbond include geotextiles, bedding, protective medical, etc [7].

2.4.3 Spunlace

This technology was officially introduced by DuPont in 1973 (Sontara®). Majorities of hydroentangled fabrics have incorporated dry-laid webs (carded or air-laid webs as precursors). This trend has changed very recently with an increase in wet-laid precursor webs. The term, spunlace, is used more popularly in the nonwoven industry. In fact, the spunlace process can be defined as: the spunlace process is a nonwovens manufacturing system that employs jets of water to entangle fibers and thereby provide fabric integrity. Softness, drape, conformability, and relatively high strength are the major characteristics that make spunlace nonwoven unique among nonwovens [7].

Spunlacing is a process of entangling a web of loose fibers on a porous belt or moving perforated or patterned screen to form a sheet structure by subjecting the fibers to multiple rows of fine high-pressure jets of water. Most commonly, precursors are mixtures of cellulose and man-made fibers (PET, nylon, acrylics, Kevlar and polypropylene).

The steps characteristic for producing hydro-entangled nonwoven fabric include: precursor web, formation, web entanglement, water circulation and web drying. **Shorter fibers** are more mobile and produce more entanglement points than longer fibers. Fabric strength, however, is proportional to fiber length; therefore, fiber length must be selected to give the best balance between the number of entanglement points and fabric strength. For PET, the fiber length from 1.8 to 2.4 seems to be best [7]. Medical and disposable apparel, garment interlinings, wipes and home furnishings are the main end-uses of spunlaced nonwovens [7]. This process is used for polypropylene products (figure 2.4).

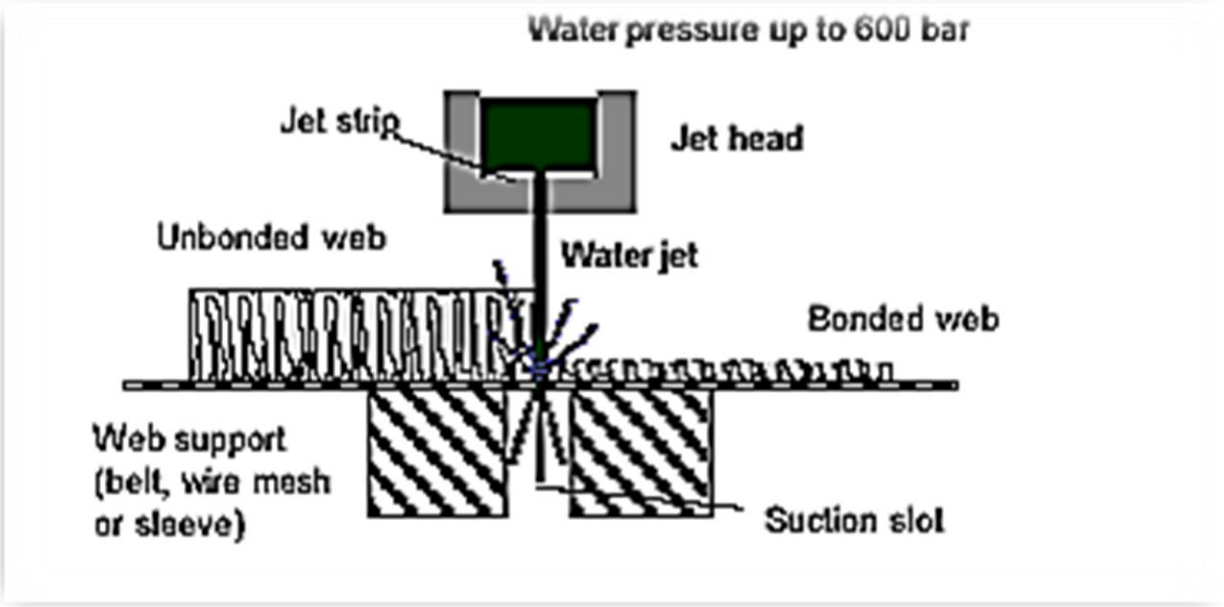


Figure 2.4: Schematic of spunlace process [7]

2.4.4 Needle Punching

The needlepunch process is the oldest process used to produce nonwovens materials and polypropylene fibers were also used (figure 2.5). Needlepunched nonwovens are created by mechanically orienting and interlocking the **fibers** of a spunbonded (filaments) or carded web (staple fibers). This mechanical interlocking is achieved with thousands of barbed felting needles repeatedly passing into and out of the web [7].

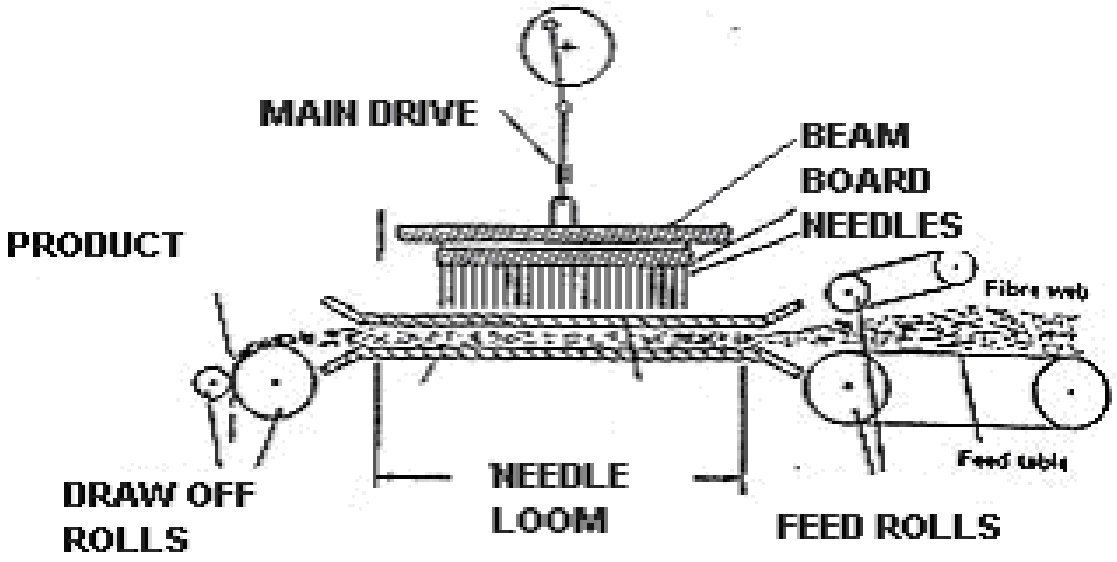


Figure 2.5: Schematic of needle punching process [7]

The most important machine variable is the depth of penetration and puncture density. The fiber travel through the web depends on the depth of penetration of the needle. The maximum penetration is fixed by the needle of the machine and depends on the length of the three sided shank, the distance between the needle plates, the height of stroke, and the angle of penetration. The greater the depth of penetration, greater is the entanglement of fibers within the fabric because more barbs are employed. The thickness, basis weight, bulking density and air permeability provide information about compactness of fabrics influenced by a number of factors. If the basis weight of the web and puncture density and depth are increased, the web density increases and air permeability is reduced (when finer needles and longer, finer and more tightly crimped fibers are used). Web density does not increase when finer fibers are needled with coarser needles. There is neither an increase nor a decrease in air permeability if the puncture density is increased [7]. Needle punched products are used in tennis court surfaces automotive carpets, filters, automotive insulators, Kevlar bullet proof vests, etc. It was also possible to use this technology for sorbents. Nonwovens textile sorbents imbibe oil by means of absorption and wicking action, therefore it is very crucial to understand the properties of these imbibing actions.

2.5 Absorption Properties and Parameters to be tested

2.5.1 Absorption Properties

Absorbency rate and absorbent capacity are the two most important performance parameters to be considered for absorbent applications of nonwovens. The absorbent capacity is mainly determined by the interstitial space between the fibers, the absorbing and swelling characteristics of the material and the resiliency of the web in the wet state. The absorbency rate is governed by the balance between the forces exerted by the capillaries and the frictional drag offered by the fiber surfaces [7]. These forces should be greater than the gravitational force because when they are equal to gravitational force the capillary action stops. The flow of liquid under capillary pressure can be modeled by Lucas-Washburn equation, as shown below:

$$h = W_c t^{1/2} \quad \text{..... (1)}$$

$$W_c = (r_c \gamma \cos\theta / 2\eta)^{1/2} \quad \text{..... (2)}$$

Where h is the liquid front position or wicking length; γ, the surface tension of liquid; η, the viscosity of the liquid; θ, the apparent contact angle of the moving front; r_c, the effective hydraulic radius of the capillaries; W_c, the wicking coefficient; and t, the time [18].

For non-swelling materials, these properties are largely controlled by the capillary sorption of fluid into the structure until saturation is reached. The absorbency rate and absorbent capacity are affected by fiber mechanical and surface properties, structure of the fabric (i.e., the size and the orientation of flow channels), the nature of fluids imbibed, and the manner in which the web or the product is tested or used. Among those factors, the surface wetting characteristics (contact angle) of the fibers in the web and the structure of the web, such as the size, shape, orientation of capillaries and the extent of bonding, are most important. Fiber linear density and its cross-section area affect void volume, capillary dimensions and the total number of capillaries per unit mass in the fabrics. Fiber crimps influence the packing density of the fabrics and further affect the thickness per unit mass that affects the absorbency of the nonwoven fabrics.

The nature of the crimps, whether it is two-dimensional or three-dimensional, also has some effect [7]. It is important to know how a material can become hydrophobic or hydrophilic through the knowledge of surface free energy.

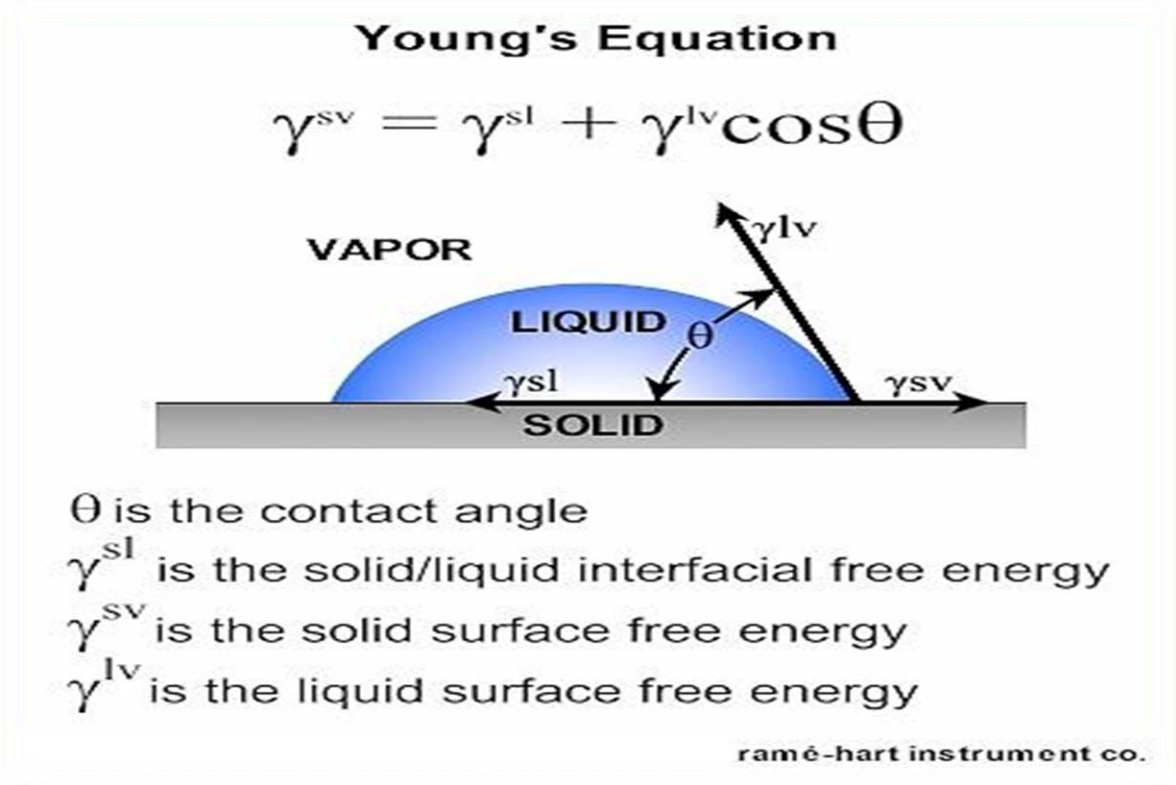


Figure 2.6: Behavior of liquid in contact with solid surface [10]

The hydrophobicity and hydrophilicity of any material can be understood more clearly by understanding the meaning of the following terms, repellency and surface tension (surface energy). The increase of the contact angle (figure 2.6) happens when the drop of liquid is not spread well on the surface and that is where material is hydrophobic but when the contact angle decreases the drop of liquid is spread well so the material is hydrophilic. Repellent materials achieve their properties by reducing the free energy at fiber surfaces. If the adhesive interactions between a fiber and a drop of liquid placed on the fiber are greater than the internal cohesive interactions within the liquid, the drop will spread (i.e. hydrophilic). If the adhesive interactions between a fiber and a drop of liquid placed on the fiber are less than the internal cohesive interactions within the liquid, the drop will not spread (i.e. hydrophobic).

Therefore, surfaces that exhibit low interactions with liquid are referred to as low energy surfaces. Their critical surface energy or surface tension (γ_c) must be lower than the surface tension of the liquid (γ_l) (the internal cohesive interaction) that is repelled. Surface tension of water is 73 mN/m, is two to three times greater than of oils (20-35 mN/m) and for polypropylene materials is 30.1 mN/m [10].

Therefore polypropylene materials repel water because surface tension of water is greater than surface tension of fibers in a material and oil is absorbed because the surface tension of fibers in a material is above than surface tension of oil.

2.5.2 Liquid absorption time and capacity

Absorbency is generally characterized by the mode and the extent of the transport of liquid into an absorbing material. There are factors that play different roles in the different absorbency characteristics:

a) Intrinsic liquid attraction capacity of the materials which determines the affinity between the liquid and the absorbent.
b) The structure of the nonwoven substances with regard to the pressure of the capillary tubes and the pore size distribution.
c) The swelling property of the material itself which affects the liquid retention property of the nonwoven [11].

Liquid *absorbency time* is the time required for a sample of absorbent material to become completely wetted by the test liquid. Liquid *absorptive capacity* is the mass of liquid that is absorbed per unit mass of the test absorbent after the time needed to wet material completely [4].

2.5.3 Liquid wicking rate

Liquid *wicking rate* is the rate at which the liquid is transported into the fabric by capillary action [4]. Moreover, wicking is a spontaneous transport of a liquid driven into a porous system by capillary forces opposite to external forces like gravity. Wickability describes the ability to maintain capillary flow on the other hand wettability describes the initial behavior of a fabric or yarn in contact with liquid. There are several techniques to study wicking properties. The first one consists of weight variation measurement by a Wilhemy balance during capillary wicking.

The second technique involves setting liquid sensitive sensors regularly along the yarns. The last focuses on observing and measuring the capillary flow of a colored liquid and the height is recorded against the time. Wicking velocity can be increased with decrease in liquid viscosity and by increasing the number of fibers in fabric area to increasing the number of capillaries. Finer fibers tend to have higher capillary absorption ability but to the detriment of liquid absorption rate compared to coarse fibers. Liquid diffusion and structural properties of nonwoven materials are strongly linked. The structural properties of fibrous materials are characterized by the fiber arrangement (packing density, fiber orientation, pore structure, etc.) as well as the fiber features (morphology, nature, surface energy, swelling, blend, etc.). The effect of the nonwoven structural properties on the liquid diffusion behavior will therefore be complex to figure out [12]. Several factors are involved in capillary action. The first is cohesion, the tendency of molecules of a substance to stick together. The second factor is adhesion, the tendency of some substances to be drawn to unlike substances. Capillary action is also less common with liquids which have a very high level of cohesion, because the individual molecules in the fluid are drawn more tightly to each other than they are to an opposing surface. Eventually, capillary action will also reach a balance point, in which the forces of adhesion and cohesion are equal, and the weight of the liquid holds it in place. As a general rule, the smaller the tube (small diameter), the higher fluid will be drawn [16]. If any textile organization is seeking to manufacture new textile sorbents it has to know almost all types of textile sorbents existing on the market.

2.6 Types of textile sorbents on the market

In Czech Republic firm Ecotextil produced sorbents for remediation application. The product-ECOSTAR textile sorbents is a convenient product for prevention and disposal of all spills arising from breakdowns and leakages in machinery and transport (figure 2.7). These sorbents are microfibrous polypropylene webs made by meltblown technology. It is their specific structure that makes their properties excellent – high adsorption capacity and good adsorption rate. Two products from Ecotextil were used for designing of sorbents that are tested in this work that is ECT and ECTU. In this research work nonwovens textile sorbents manufactured by Ecotextil were to be pleated using ROTIS II machine in order to increase thier absorptio

efficiency.

Figure 2.7: Nonwoven Textile Sorbents manufactured by Ecotextil [15].

2.7 Pleated Products

Pleated materials are very important in liquid absorption because they maximize the surface area therefore improving absorption ability of a fabric while keeping the pores fixed. The compression is another important parameter in pleated materials because the high compression it means many folds with smaller distance between two pleats therefore capillary is efficient. Pleating thin fabric is important for increasing fabric thickness whereby it is hard to be achieved by technologies of spunlace, spunbond and meltblown during manufacturing process [17]. There are three different types of vertically pleats: V shape on the left, U shape middle and drop shape pleat on the right (figure 2.8), each type has its own application.

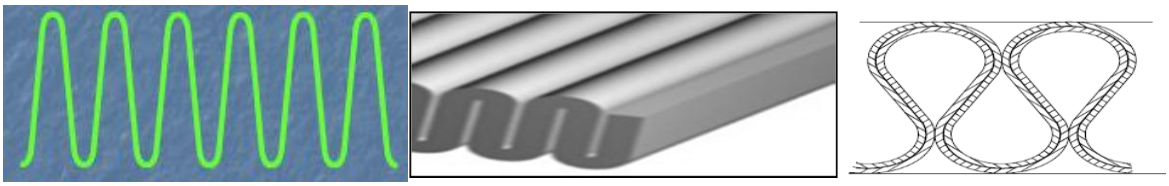


Figure 2.8: Different types of pleated products [17]

The V shape pleat width increases continuously from the top to bottom and is used for production of filters (enlarges efficiency). The U shape pleat width is constant within whole pleat height and is used for production of mattresses, noise and thermal insulation because of relatively high pleat density. The drop shape pleat width is changing with its height in such a way that is extending continuously to its widest part and is narrowing again up to its narrowest part. This drop shape increases friction between single layers of the product and the cavities formed may decrease the density and insulation properties [17]. It is convenient for production of multilayer products and is used in this work.

2.7.1 ROTIS II Machine

ROTIS II machine is the European patent used in making pleats of thin nonwoven textiles (figure 2.10). It makes the folding (pleats) by tooth rollers (input roller) which are situated in the upper part of the machine (figure 2.9). The density of the pleated material depends on to two velocities, velocity of input rollers and the velocity of output rollers (transporter). Therefore, for less density material output velocity must be higher for high density output velocity must be lower. Quasi yarns are made from free ends fibers caught by rotating spinning elements and spun together (figure 2.9). If the strength of quasi yarns is not good enough it can be supported by plastic nets for reinforcement. Quasi yarn can be easily formed to those nonwoven materials that are made from staple fibers (free ends fibers) compared to filaments fibers (no free ends fibers). For example, surface of spunbond and meltblown products are without free end fibers and quasi yarns have poor strength while needlepunch and spunlace products are having surface with free end fibers and therefore good quasi yarns with adequate strength are formed.

Quasi yarns can be made from both sides or from one only. Product fixed from one side was used in this work. A specific property of such one side product is self-tapping in a roll. This effect was used also by designing of tubular sorbents.

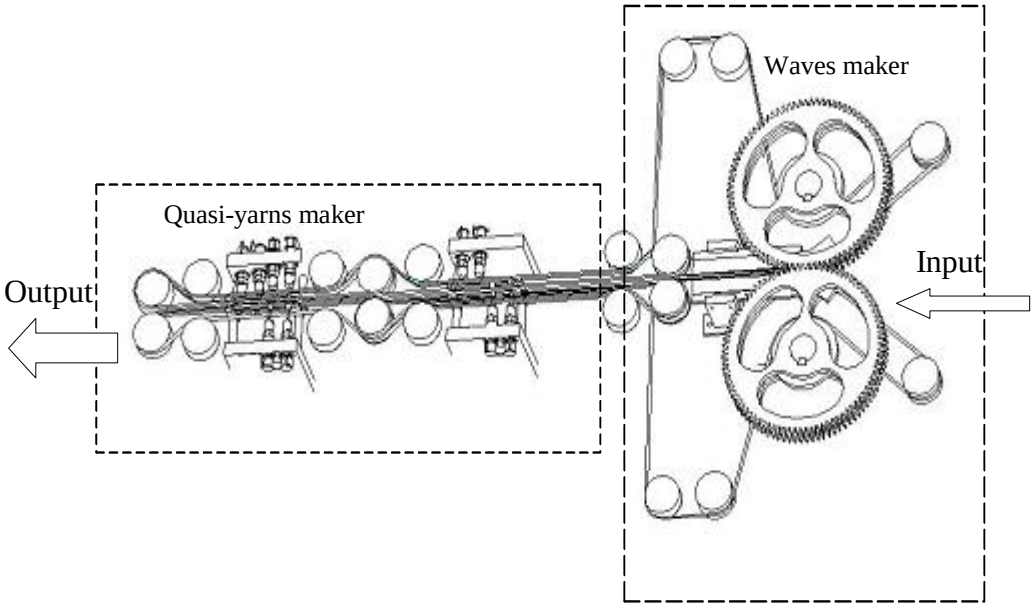


Figure 2.9: Schematic diagram of device for manufacturing products being vertically pleated from thin nonwoven fabrics [17].

Figure 2.10: Machine model for manufacturing the vertically pleated textile fabrics 4-7mm thick and about 200mm width [17].

Chapter 3

3. Experiments

The main aim of experiment is to test oil absorption efficiency of designed models of textile sorbents for remediation wells. This test will be based on absorption capacity and absorption rate of used materials-on plain strips and on models of tubular sorbents made from pleated materials. Lastly is to laboratory simulate how does the tubular sorbents will behave in nature (drilled remediation wells).

3.1 Basic nonwovens used for experimentation

Products of Czech firm Ecotextil-ECT and ECT U materials were both combined with product made by jet-lace technology (Rieter in France) R15 for fixing meltbown materials since it has got free ends fibers which are responsible for making quasi yarns. Materials used for experiments were ECT MB (meltblown) white, ECT U MB (meltblown) grey (both 130-229g/m^2) and R15 (spun-jet 60gm^{-2}) for fixing (increase sorbent strength) only. All these materials were made from polypropylene polymer whereby ECT and R15 are both hydrophobic while ECT U material is both hydrophilic and hydrophobic which means it absorbs oil, water and water soluble chemicals. The technical data parameters are shown in the table 3.1 below.

Table 3.1: Technical data parameters

Sample	Composition	Weight [g/m^2]	Thickness [mm]	Absorption Capacity [l/kg]
ECT MB*	Polypropylene	130-229	2	18-20
ECT U MB**	Polypropylene	130-229	2	10-12
R15	Polypropylene	60	0.5	

Remarks: Material real names according to technical data sheet of Ecotextil are as follows:
*(AOLWM): Absorbent Oil Light Weight Meltblown; **(AWLWM): Absorbent Water Light Weight Meltblown [15].

Testing mediums

The mixture of spent (used) engine **oil**, 10W-40 SAE with viscosity of 30,35Pa or 0.152Pa.s at 21^oC and tap **water.**

3.2 Designing and making sorbents for tests

Parameters of the ROTIS machine were set as follows: output velocity was 2m/min, wavenumber forming of a product was calculated to be 2.4/cm which gave thickness of product, the machine setting wave forming was 0.60 which worked for sorbent production. The voltage of the fixing element motors was 12 volts and lastly the distance between the fixing plates was set to be 6.5mm.

Two plane samples (R15 with ECT or ECT U) from single layer materials were placed together and then inserted between the two rotating toothed rollers at the top part of ROTIS machine (figure 2.10) to form pleats (converting plane materials to wave form). This is due to the fact that toothed top rollers and transporter plates are rotating at different velocities. The pleated form is formed at the rollers and then transported downward by the transporter plate. Tubular sorbents were made by hand using hollow long cylinder made from plastic for sizing and shaping. The pleated material was rolled up to the roll, the weight and diameter of which were checked. The hollow cylinder ensured almost constant diameter among the tubular samples and also responsible in making the sample heavier or lighter. Plastic net were used to give strength to the samples and for giving different densities of the samples. The size of sorbents produced had the following dimensions: diameter 50mm and length 250mm. The overview of the samples tested is summarized on table 3.2 below.

Table 3.2: Overview of the samples for tests with their parameters.

Sample form and dimension sizes [mm]	Material and design	Density [kg/m^3]	Testing Medium	No. Samples	No. of tests
Strips Length: 250 Width: 30	Flat 100% ECT Thickness 2 mm	82	Oil	5	1
	Flat 100% ECT U Thickness 2 mm	82	Oil	5	2
			Water & ink	5	3
	Flat R15 Thickness 0.5 mm	120	Oil	5	4
Tubular short test in oil Diameter: 52-54 Height: 120-124	Pleated ECT +R15 Light and Heavy	78	Oil	4	5
		104	Oil	4	6
	Pleated ECT U +R15	80	Oil	4	7

	Light and Heavy	98	Oil	4	8
Tubular long weight test Diameter: 47-50 Height: 236-245	Pleated ECT +R15	83	Oil	1	9
	Light and Heavy	120	Oil	1	10
	Pleated ECT U +R15	90	Oil	1	11
	Light and Heavy	106	Oil	1	12
Tubular long oil-water standard test 24 hrs. **S24** Diameter: 50-55 Height: 250-251	Pleated ECT +R15	80	Oil + water	5	13
	Light and Heavy	94	Oil + water	5	14
	Pleated ECT U +R15	81	Oil + water	5	15
	Light and Heavy	118	Oil + water	5	16
Tubular long oil-water compare test 24 hrs. **C24** Diameter: 50-54 Height: 250-253	Pleated ECT +R15	83	Oil + water	1	17
	Light and Heavy	98	Oil + water	1	18
	Pleated ECT U +R15	77	Oil + water	1	19
	Light and Heavy	109	Oil + water	1	20
Tubular long oil-water long test 13 days **L13** Diameter: 50-55 Height: 250-255	Pleated ECT +R15 Light and Heavy	72	Oil + water	1	21
		92	Oil + water	1	22
	Pleated ECT U +R15	70	Oil + water	1	23
	Light and Heavy	100	Oil + water	1	24
Tubular long start water–oil long test 7 days **L7** Diameter: 48-51 Height: 240-256	Pleated ECT +R15	81	Water + oil	1	25
	Light and Heavy	115	Water + oil	1	26
	Pleated ECT U +R15	83	Water + oil	1	26
	Light and Heavy	114	Water + oil	1	27

Remarks: No. refers to number of tested samples and tests carried. Start water-oil long test 7 days means start with water only in cylinder put samples then and oil on the next day and oil-water test means sample was put in cylinder where there was oil on water level. Light refers to low density and heavy to higher density. Oil-water test means water on oil in one measuring cylinder before inserting the sample while start water-oil test means water first in measuring cylinder before inserting sample then add oil one day later after sample is inserted in cylinder.

3.3 Testing of sorbents

3.3.1 Plan of the tests

The flat strips of hydrophobic ECT and hydrophilic ECT U polypropylene nonwoven will be used to test the ability of materials to absorb oil and water in the case of the used nonwoven that possesses both hydrophobic and hydrophilic properties. The ROTIS machine will be used to make pleats on a nonwoven to increase surface area for better absorption. The pleated materials will be then rolled to form a tubular product that has got relatively high sorption capacity compared to flat strips. Tubular products will go under different tests which are as follows: capillary action tests that include absorbing oil in container and absorbing oil in container but this one placed on weighing balance, the absorption and capillary action test that includes oil on water in a measuring cylinder (simulation of drilled wells) including the following tests: oil-water standard test 24 hours, oil-water compare test 24 hours, oil-water long test 13 days and start with only water then oil test 7 days. Absorption rate and capacity will be measured for all these tests and the sorbent efficiency analysis will be done graphically. The overview of the planned test is shown on table 3.3 below.

Table 3.3: Overview of the planned tests

Type of tests	Form of sample	Testing medium
Wicking from container	Flat strips	Oil
		Oil + Water
	Pleated Tubular	Oil
Wicking from container on weight scale	Pleated Tubular	Oil
Wicking and Absorption (test in measuring cylinder) include: Oil-water standard test 24 hrs. Oil-water compare test 24 hrs. Oil-water long test 13 days. Start water–oil long test 7 days.	Pleated Tubular	Oil + Water

3.3.2 Tests of strips

Five strips were cut from each material in dimensions 250 x30 mm and 15 mm length was measured and marked on 250 mm sides in each strip see number of tests (1-5) table 3.2. 15mm is the length that has to be submerged under level of oil. The mass of each strip was measured before it was put into oil. The strips were clamped as shown in figure 3.1 below. Containers of oil were marked in order to ensure that oil is in same level. The dots that are shown on strips (figure 3.1) were 20 mm apart and were measured just above the level of oil. R15 (5 strips) and ECT (5 strips) were all put into oil at the same time and then height of oil absorbed was measured for these time frames in hours (0.1, 0.3, 0.7, 1.0 -5.0 and after 24 hrs.) see table 4.1 in chapter 4.

The behavior of oil for both materials was observed and it was seen that the level of oil on strips was not at the same level of both sides (figure 3.1 b) so the height was measured half way between top and bottom points.

For ECT U material only, two tests were done in both oil and ink color water because this material has the ability to absorbed both oil and water. Therefore, ten strips were cut and five of them were put in oil and other five in water (figure 3.2). Same method was carried out as it was done for ECT and R15 materials but here, the height of oil and water was measured at the front and back because the ECT U material is rough at the back and smooth at the front (figure 3.2 and 3.3). The materials were allowed to stay in liquids for 28 hours. Liquids were added into containers to keep oil or water in the same level throughout the experiment.

After 24 hours each strip was removed out of oil and then allowed to stand for 30 seconds. The 15mm part which was submerged under oil or water was cut in each strip and then more than four 20mm parts were also cut but only the wet part (figure 3.4). The mass of each cut strips was measured and recorded. Two graphs were plotted whereby material behavior were compared, one graph was for height against time and second one for gram oil/gram textile against the parts of cut strips that absorbed oil.

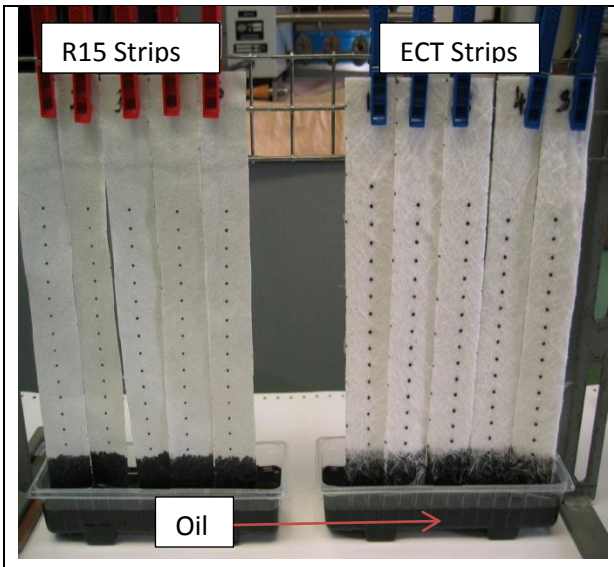


Figure 3.1 (a): R 15 and ECT sorbents at the beginning of oil absorption tests

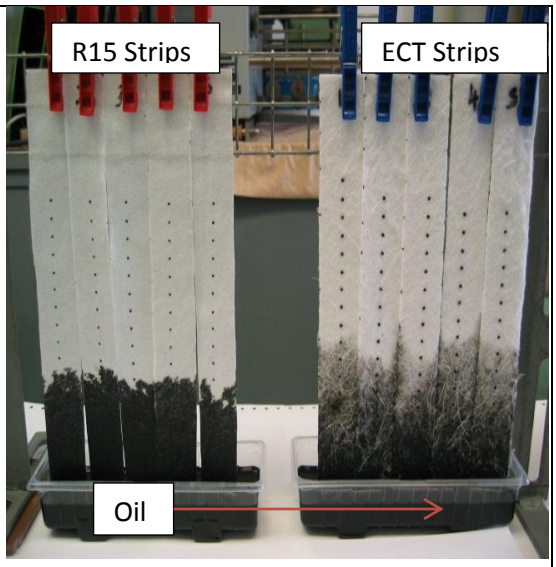


Figure 3.1 (b): R15 and ECT sorbents after 5 hours in oil

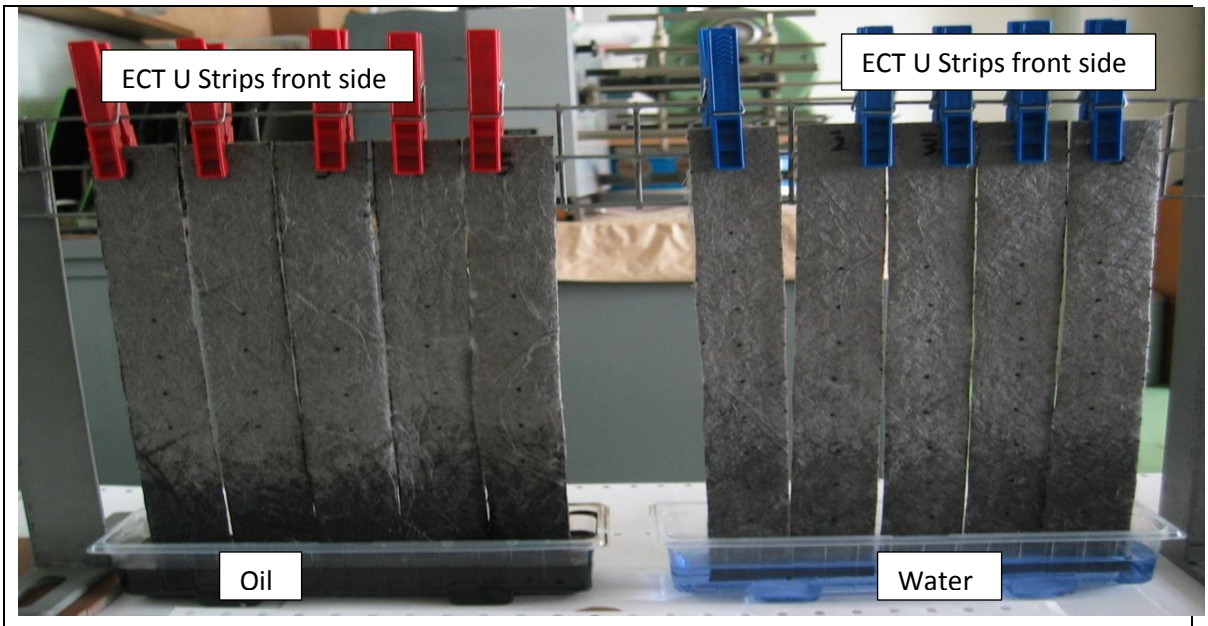


Figure 3.2: Front side ECT U sorbents in oil and water separately containers after 6 hours

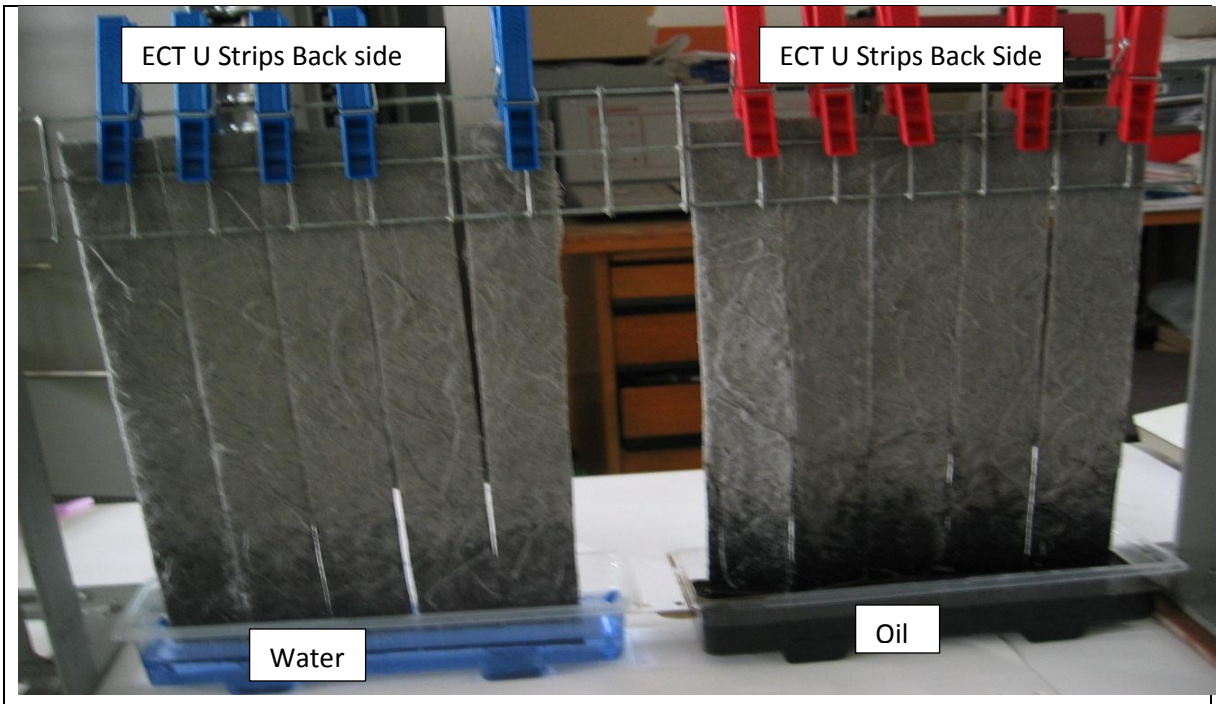
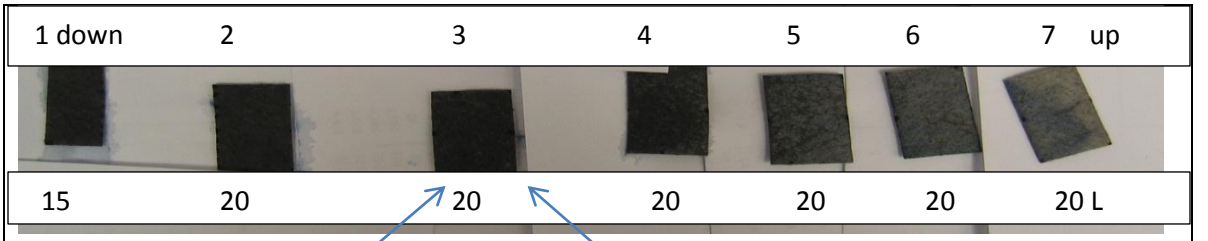
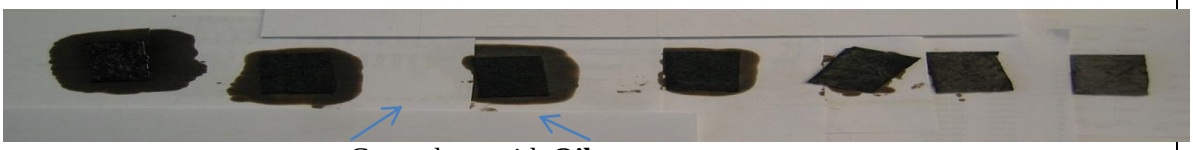


Figure 3.3: Back side ECT U sorbents in oil and water separately containers after 6 hours



Down suction foot Cut sorbent with **Water** Upper part



Cut sorbent with **Oil**

Figure 3.4: ECT U cut strips with oil and water absorbed separately. Detailed results in chapter 4.1

3.3.3 Tests of tubular sorbents

3.3.3.1 Tests in oil

During testing, each type of a short tubular sample had four duplicates see number of tests (5-8) of samples table 3.2 above, therefore the total number samples was sixteen and the samples were assembled as shown below (figure 3.5). The method of taking measurements was repeated as it was done for strips experiments and the same graphs were plotted (chapter 4). In addition to measurements, the height and the diameter of the cylinder were measured with an aim to calculate the exact volume and the density of each sample. Samples were removed from oil after 24 hours and one sample from each type was chosen for unrolling and then cut into three parts (41 mm each down, middle and up) (figure 3.7). The mass of each part (oil and textile) was measured with an aim for calculating the amount of oil in a textile material.

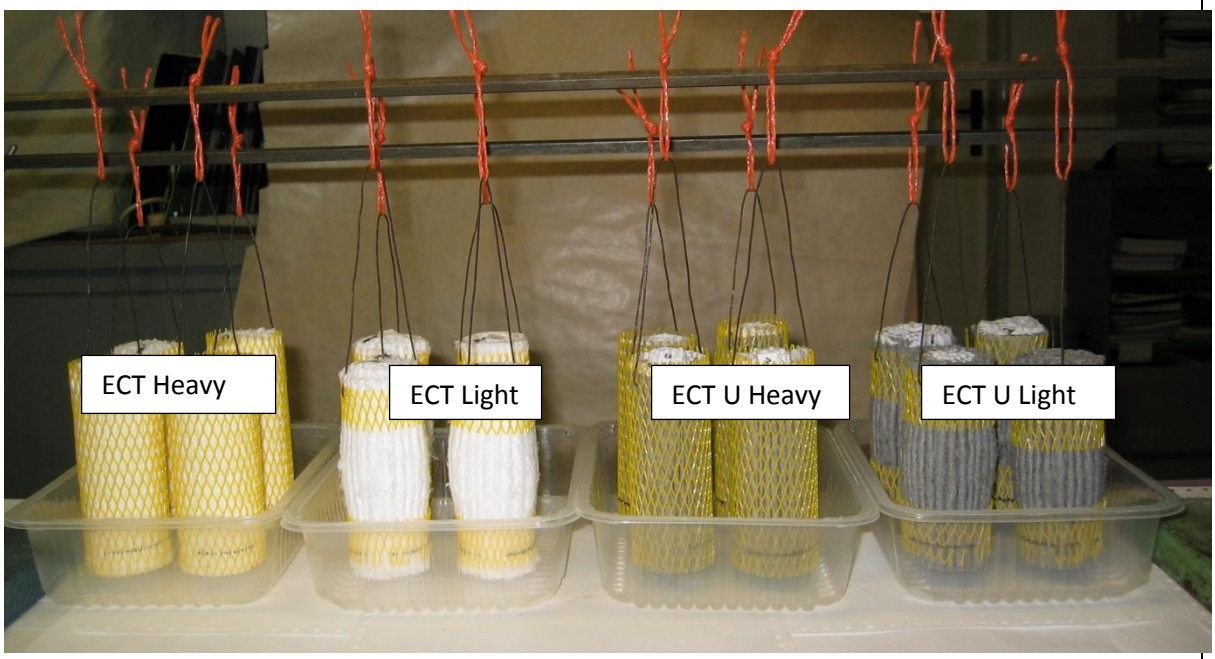


Figure 3.5: Assemble of short tubular sorbents before put into oil (125 mm short sorbents)

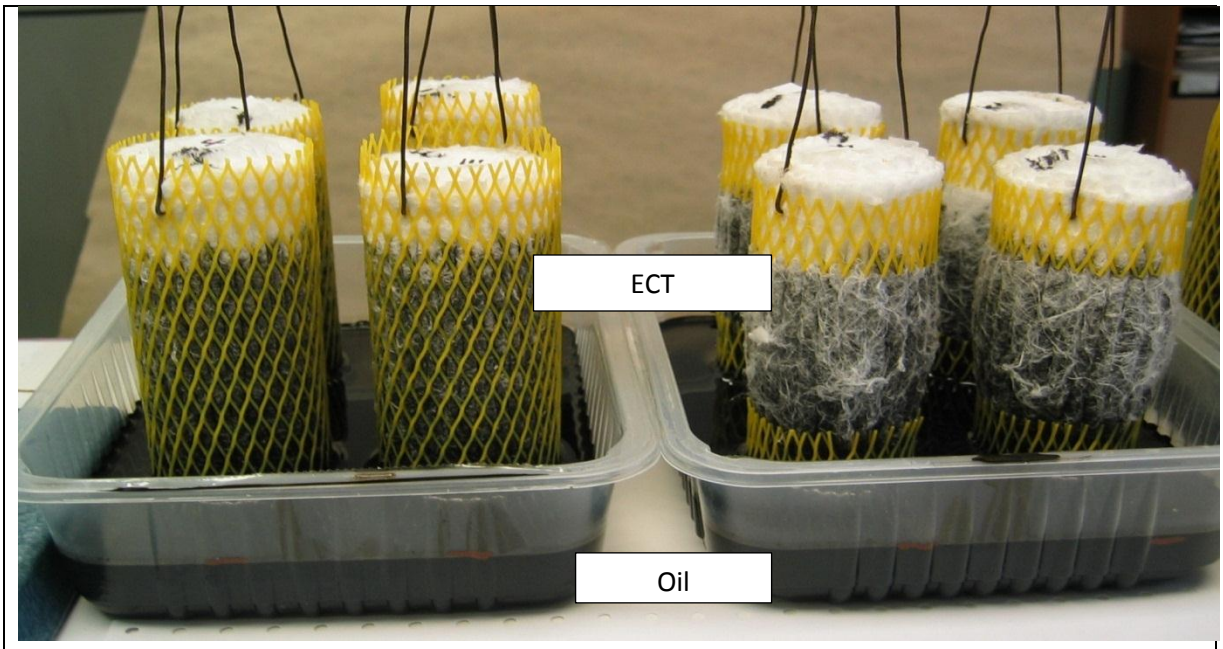


Figure 3.6: ECT tubular sorbents heavy and light after 4 hours in oil (125 mm short sorbents)

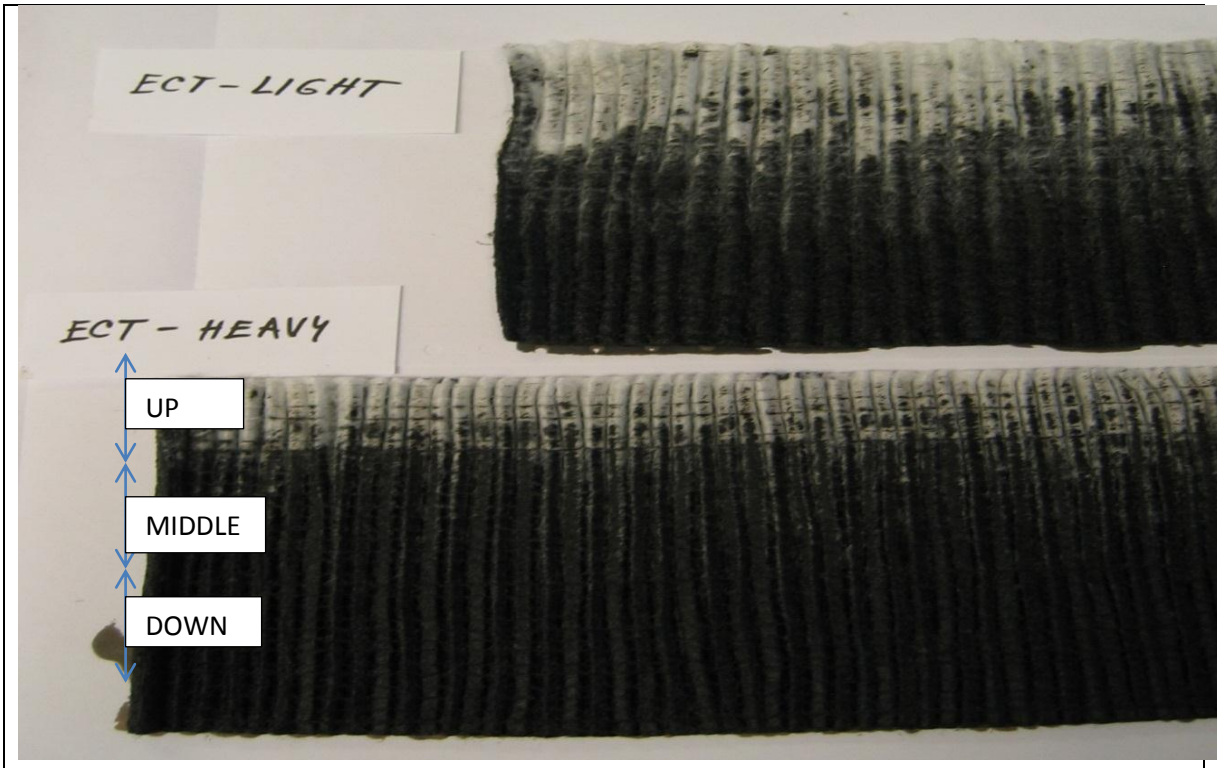


Figure 3.7: Unrolled cylindrical sorbents ECT before cutting with marked places for cutting (up, middle and down)

3.3.3.2 Weight tests

Only four samples were used in this test (one ECT light and heavy samples and one ECT U light and heavy samples) see number of tests (9-12). Firstly, sample was hanged on a stand with adjustable (free to move up and down and sides ways) clamp. The mass of empty container was measured and then oil was poured into it see table 3.4 below. The mass of container with oil was also measured using the digital weighing balance. The sample was moved downwards slowly using adjustable clamp to submerge 15mm marked part of the cylindrical sample under oil (figure 3.8). Immediately just after submerging sample under oil the reading on a weighing balance was recorded and then after 2minutes the level of oil getting into the sample was measured (height of oil absorbed). At the same time the reading on the weighing balance was measured. The readings were further taken in these time frames (5, 10, 20, 30, 45 minutes, 1-7 hours and 24-25 hours). Touching the level of oil during height measuring was avoided as some of the oil would stick on measuring instruments. It was highly necessary to move the sample down while the oil is being absorbed into the material to ensure that marked 15 mm part is always submerge under oil (full attention was required). After 25 hours the sample was moved up out of the oil for 30 seconds and then it mass (textile and oil) was weighed and recorded. The sample was unrolled whereby the wet part was divided into three parts by cutting perpendicular to the pleats (down, middle and upper). The mass of each part was also recorded. Gram oil per gram textile was calculated for these cut parts and the amount of oil absorbed was calculated. The same types of graphs were plotted as it was described in section 3.3.2 above. Mass of oil measured by a weighing balance scale is shown on a table below.

Table 3.4: Mass of oil measured on weight measuring scale just after inserting the sample.

Sample	Mass after [g] (MSI)
ECT Heavy	399.48
ECT Light	372.68
ECT U Heavy	371.89
ECT U Light	361.45

Remarks: MSI-mass on scale just after sample insertion see page 64.

Mass of oil measured from the weighing scale just after inserting the sample were used to calculate the amount of oil that is absorbed by a sample as the time proceeds. This is shown on table 4.9 and figure 4.8.

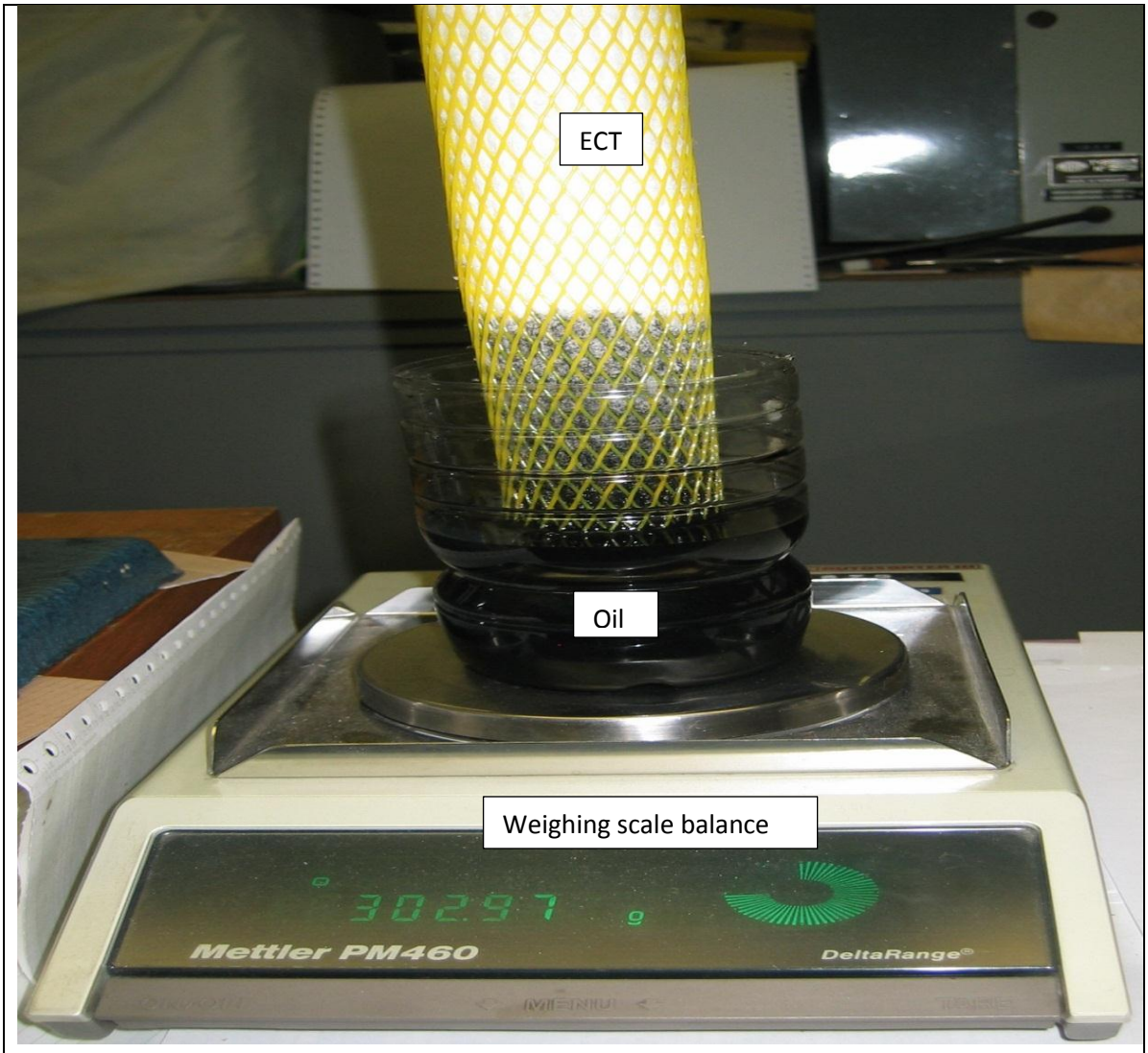


Figure 3.8: ECT tubular sorbents hanged over the weight (250 mm long sorbents)

3.3.3.3 Tests in measuring cylinder (volume test)

This is the most interesting experiment in this work because it explains the behavior of tubular sorbents in wells since it is similar to practical applications. Five samples were used for each kind of sorbent textiles (ECT heavy and light, ECT U heavy and light samples) (figure 3.10) and see number of tests (13-16) table 3.2. The samples used were approximately 250 mm long with a diameter approximately 52 mm for heavy samples and 56 mm for light sample. Measuring cylinder (1000 ml) was used for taking measurements for each sample whereby 750 ml of water and 200 ml oil were poured into cylinder (figure 3.11 a). This amount of water used to ensure that water height is more than the length of sample to give allowance if sample will be submerged under water level therefore water height in a cylinder was measured to be approximately 25 cm or more. Moreover, amount oil used was to ensure that the sample takes at least 5 to 7 minutes to absorb whole 200 ml.

The sample was dropped into the measuring cylinder containing both oil and water at the same time was measured both levels of oil and water rose due oil and water displacement by sample (figure 3.11b). For each and every minute the measurements were taken up until whole 200 ml is absorbed (from 1 to 7 minutes at most). Besides measuring time other important measurement were taken by taking volume readings (ml) on a measuring cylinder which include the following: **oil volume, water volume and the bottom part of sample as it goes down** (expressed in ml it tells us how quick sample moves down) (figure 3.9). More oil about 230 ml was added into a cylinder after 7 minute (when 200 ml is absorbed) but it was not added at once. But 23 ml syringe with long small tube (to ensure that oil does not touch the sample) was used to do addition (10 times) after every 3minutes starting (figure 3.11c) from 5 or 7 minutes up until 35 minutes was reached. After this time measurements were taken after every 5minutes up until 60minutes then after this time, the time frames were switched to be as follows: 70, 80, 120 (2 hours), 1200, 1260 and 1440 minutes last one. The sample was taken out of cylinder after 24 hours then its mass was measured (oil together with sample) after being full (reaching its maximum capacity) (figure 3.12 a).

The sample was then unrolled and cut into 4 equal parts (up, middle1, middle2 and down) (figure 3.12 b). The mass of each part was also measured for gram oil per gram textile calculations. The oil on side of cylinder was allowed to settle down on water which takes more than 10 hours because measurements were taken on the next day.

The volume of water and oil in a cylinder after 24 hours (after sample is removed) were measured. For all other samples same procedure was followed.

Averages of measured data for every type of a sample were taken and used to plot required graphs for conclusion be drawn.

All four different types of samples (see number of tests 17-20 table 3.2) were also run at the same time and all measurements were taken simultaneously for comparing the behavior of different samples (figures 3.13 and 4.14) and appendix table 8.19 for details. Other tests carried include oil-water long test 13 days (figures 3.14 and 4.15) and appendix table 8.20 for details, and start with water then oil long test 7 days (figures 3.15 and 4.16) and appendix table 8.21 for details. The very same procedure explained above was applied in these tests except addition of oil that was added after a very long time for these last two tests see test number 13-16 table 3.2.

In this particular test number 17-20 table 3.2 all measurements were carried in a time frame of 24 hours, but for the last two tests were carried in a time frame of more than 5 days see number of tests (21-27) on table 3.2. The aim of these long period tests was to see the behavior of four different samples if they stay long time in water after oil absorption and if oil comes in different portions up until sample gets full. Here the test started with 750 ml of water and 200 ml of oil, then after two 48 hours 115 ml of oil was added into the cylinders and allowed to stay for many days as outlined on table 3.2. After this period another 115 ml of oil was added after 96 hours and sample was allowed to stay in liquids 9 days more. Unrolling and cut of samples was done in these tests together and measuring the volume of oil and water in cylinder after 7 or 13 days (after sample is removed). It is interesting to show the two dimensional view for measurement taking as shown in figure 3.9 below. **In all measuring cylinder tests total amount of oil poured into each cylinder sorbent test is 430 ml.**

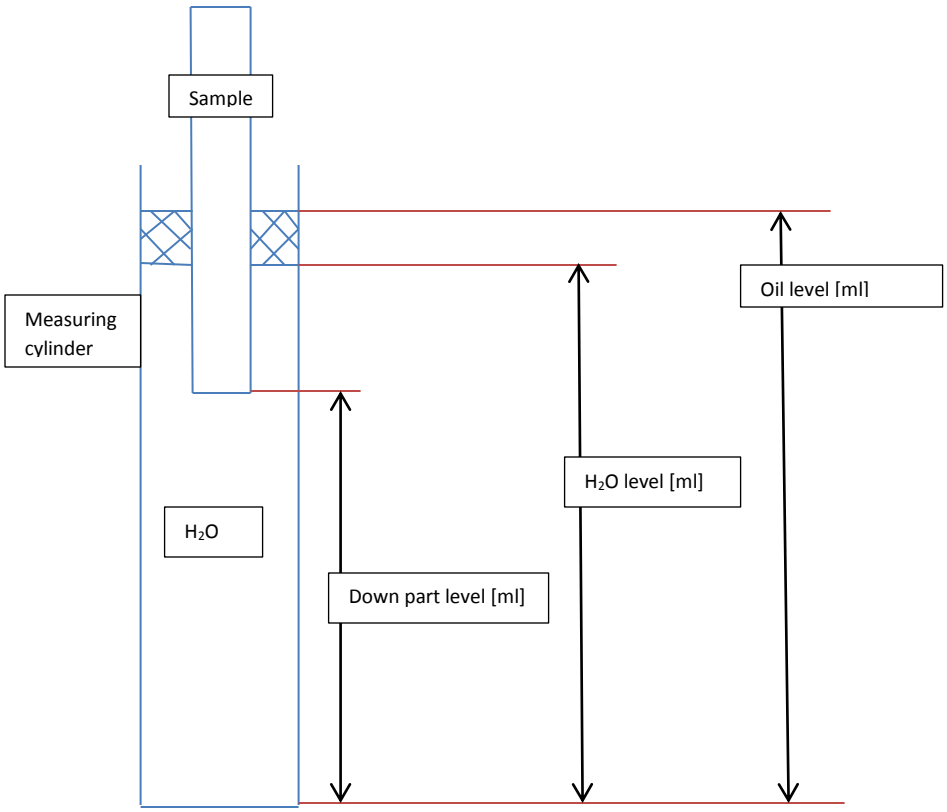
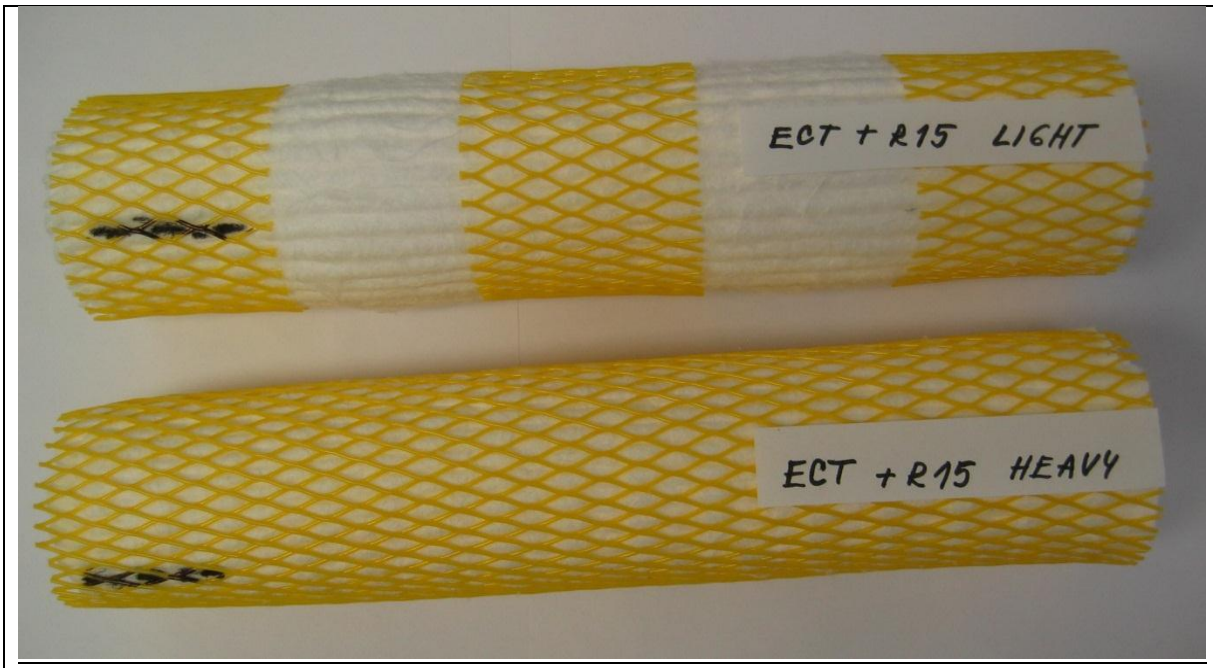


Figure 3.9: Schematic for showing how measurements were taken for tests in measuring cylinder (volume tests)



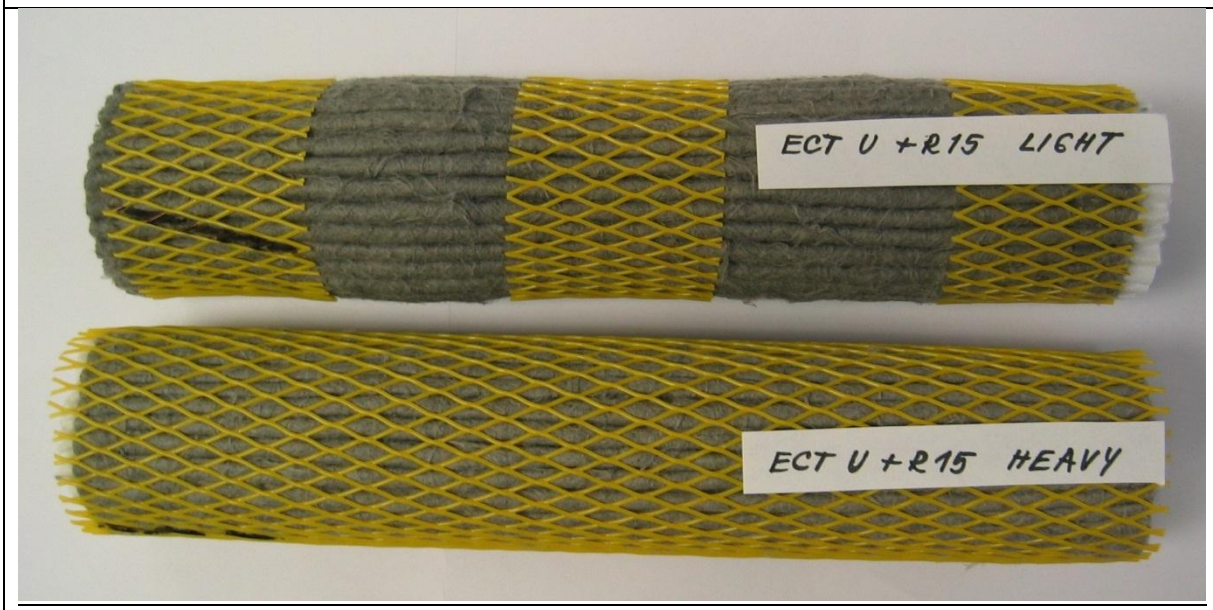


Figure 3.10: Different types sorbents used in measuring cylinder (volume test) (250 mm long sorbents)

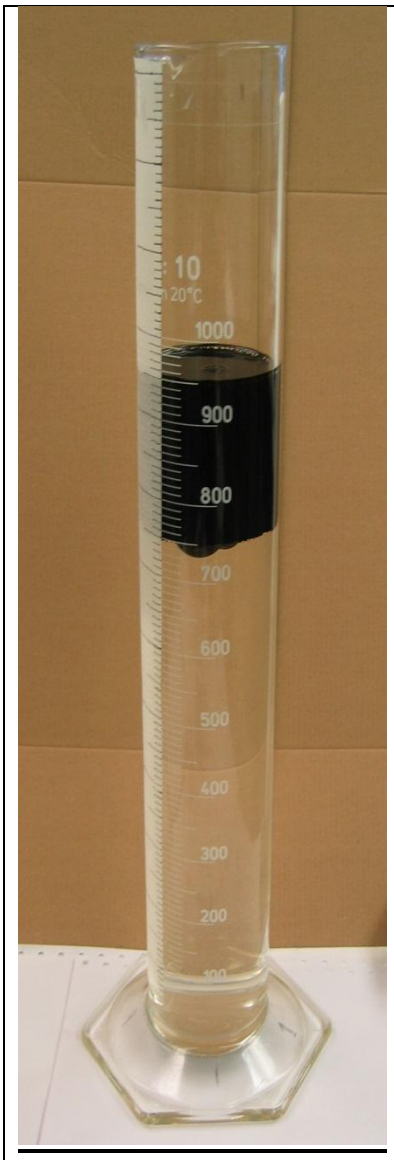


Figure 3.11 (a): Oil-water standard test at the beginning of test

Figure 3.11 (b): Sample in a cylinder few minutes after inserted

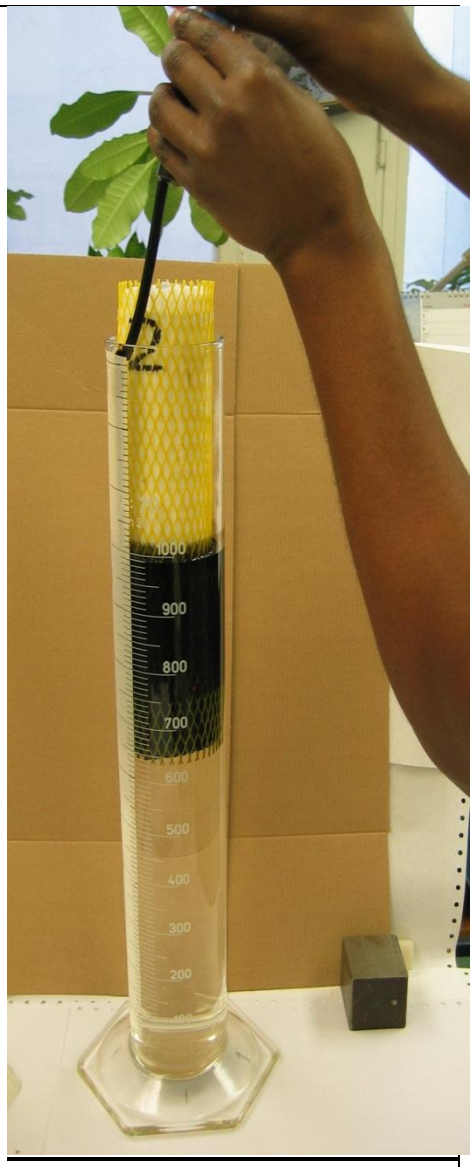


Figure 3.11 (c): Addition of oil using 23 ml syringe

Figure 3.12 (a): Sample full of oil after 21 hours

Figure 3.12 (b): Unrolled ECT heavy sample with marked places for cutting (down, part 2, part 3 and up)

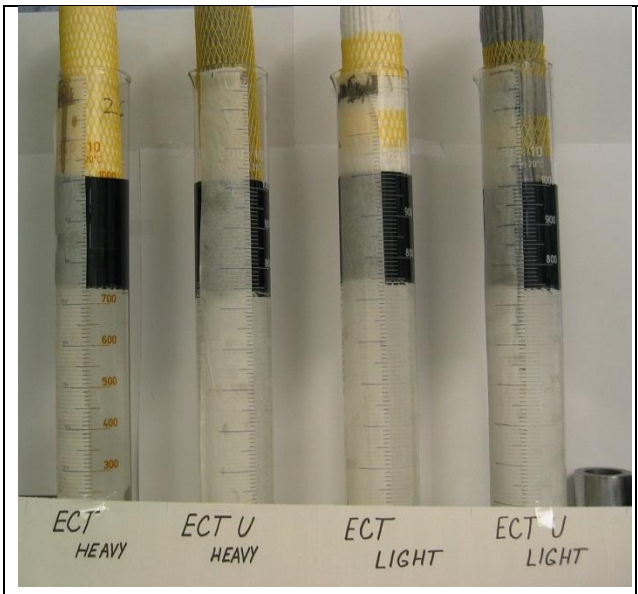


Figure 3.13 (a): Oil-water compare test at the beginning.

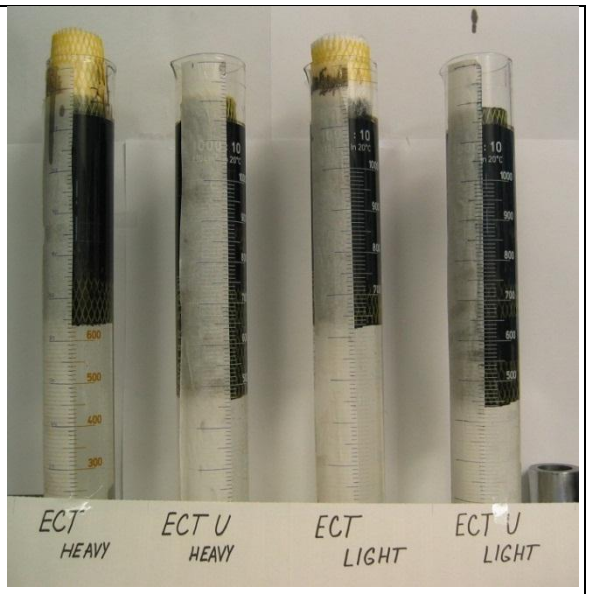


Figure 3.13 (b): Oil-water compare test after 35 minutes.

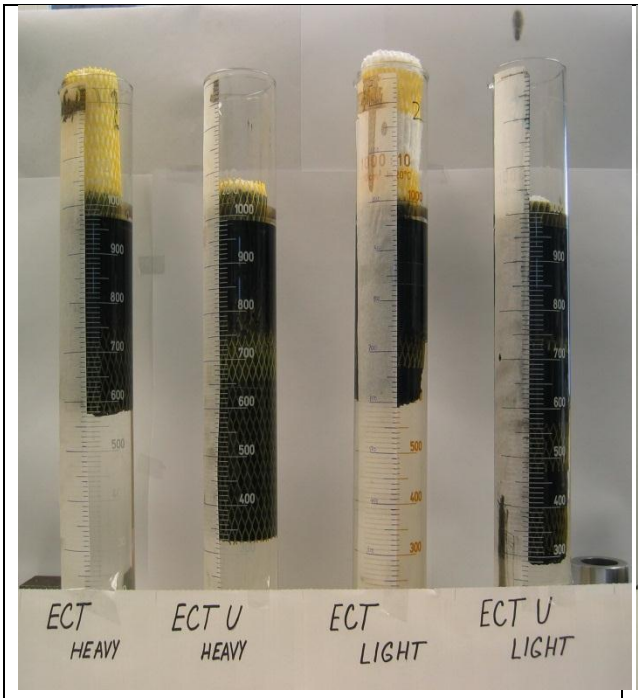


Figure 3.14 (a): O**il-water long** test after 2 hours.

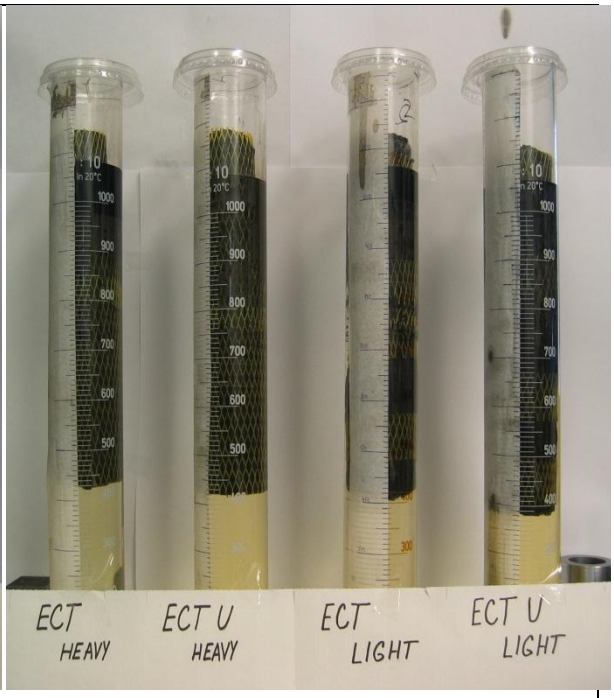


Figure 3.14 (b): **Oil-water long** test after 13 days.

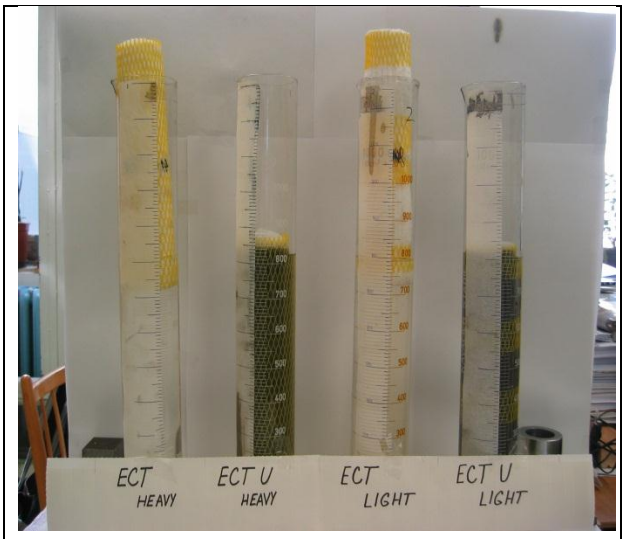


Figure 3.15 (a): **Start water-oil long** test at the beginning.

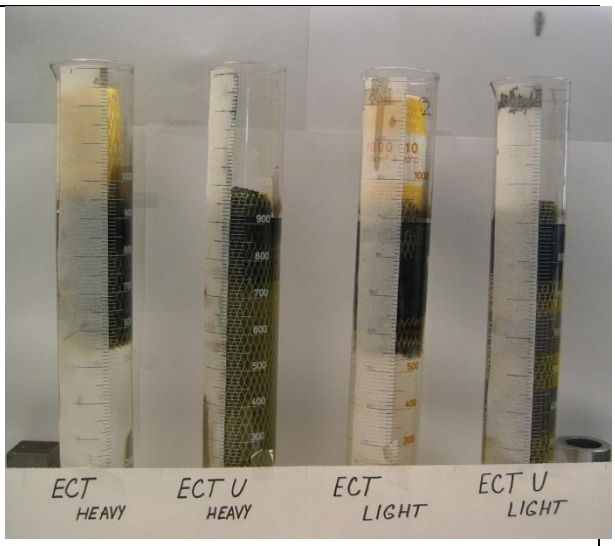


Figure 3.15 (b): **Start water- oil long** test after 24 hours.

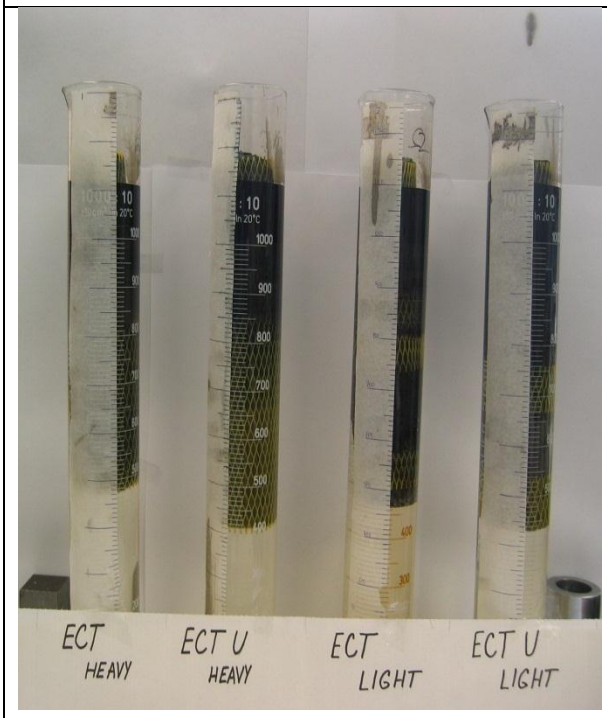


Figure 3.15 (c): **Start water- oil long** test after 7 days.

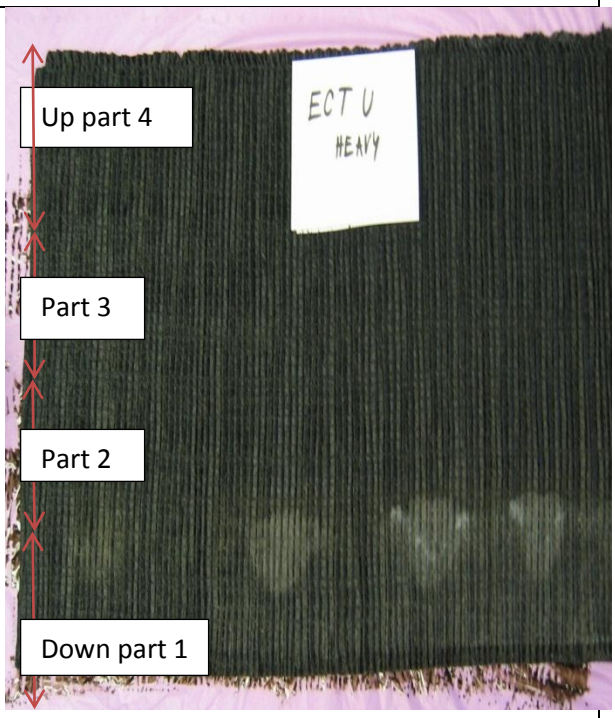


Figure 3.15 (d): **Start water- oil long** test for unrolled ECT U heavy sample.

Chapter 4

4. Results and Discussions

4.1 Strip Tests-results

The tests of these strip tests-results are described in chapter 3.3.2 while the tables and graphs shown on figures below present the results of those tests.

Table 4.1: Height of oil absorbed for sorbents R15 and ECT

ECT		R15	
Time [hrs.]	Height $\bar{y}$ [mm]	Time [hrs.]	Height $\bar{y}$ [mm]
0.17	39.20	0.08	32.40
0.42	49.60	0.33	43.40
0.67	57.80	0.67	51.20
1.00	66.20	1.00	57.40
2.00	76.60	2.00	64.80
3.00	84.20	3.00	68.60
4.00	6.20	4.00	71.40
5.00	89.80	5.00	73.60
24.00	114.00	24.00	77.20

Table 4.2: Height of oil and inked water absorbed separately for sorbents ECT U

ECT U oil (front side)		ECT U oil (back sides)		ECT U water + ink (front side)		ECT U water + ink (back side)	
Time [hours]	Height $\bar{y}$ [mm]	Time [hours]	Height $\bar{y}$ [mm]	Time [hours]	Height $\bar{y}$ [mm]	Time [hours]	Height $\bar{y}$ [mm]
0.17	32.80	0.25	31.00	0.17	55.80	0.25	47.60
0.42	41.40	0.50	40.60	0.42	63.80	0.50	56.40
0.67	48.00	0.75	47.40	0.67	70.00	0.75	65.00
1.00	52.80	1.00	51.20	1.00	73.40	1.00	67.60
2.00	58.80	2.00	56.00	2.00	78.40	2.00	69.00
3.00	66.60	3.00	63.20	3.00	78.80	3.00	67.60
4.00	70.80	4.00	67.00	4.00	82.00	4.00	68.60
5.00	72.40	5.00	68.00	5.00	83.00	5.00	69.40
6.00	74.60	6.00	69.20	6.00	84.60	6.00	70.00
24.00	76.00	24.00	72.60	24.00	116.00	24.00	70.00
28.00	76.00	28.00	72.60	28.00	116.00	28.00	70.00

Remarks: For table 4.1 & 4.1: Mean ($\bar{y}$) from 5 samples. Time was fixed therefore no mean for it. The details of five measurements for tables 4.1 and 4.2 are shown in the appendix table 8.2-8.5.

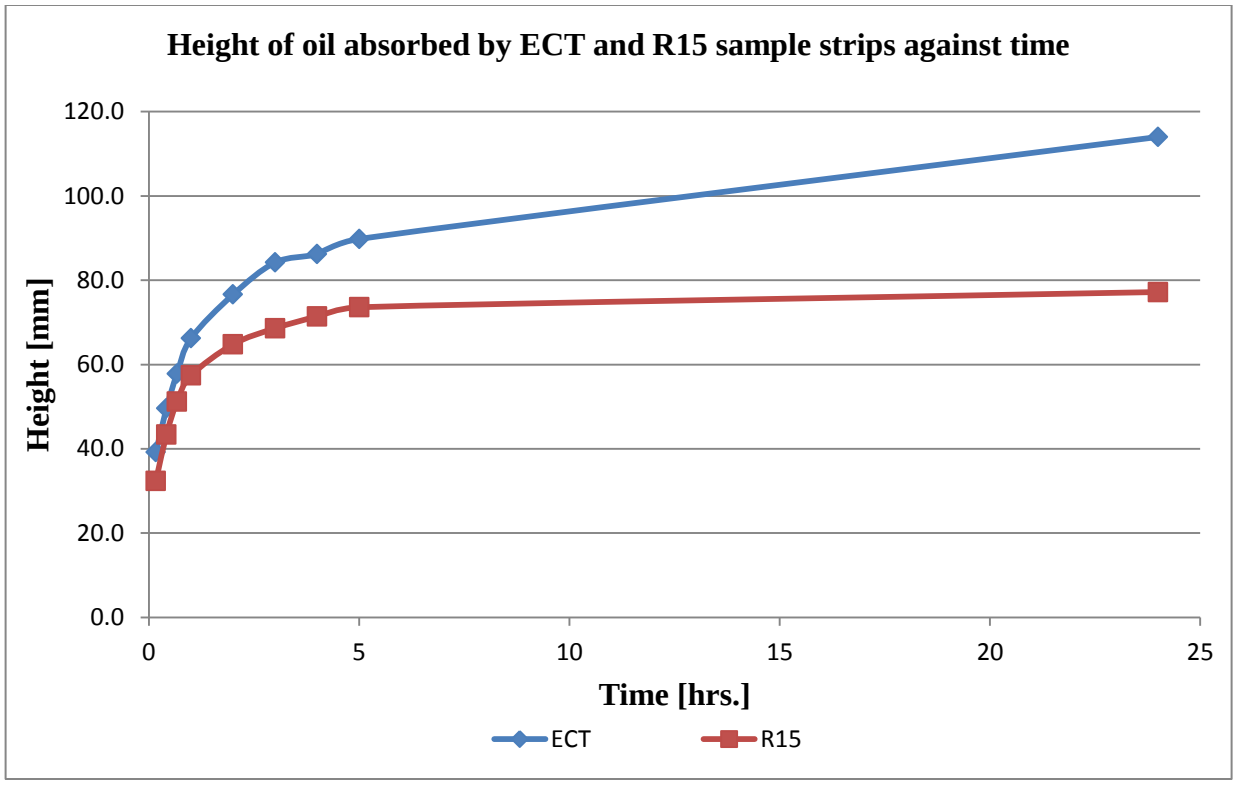


Figure 4.1: Height of oil absorbed by plane strips of ECT and R15 samples

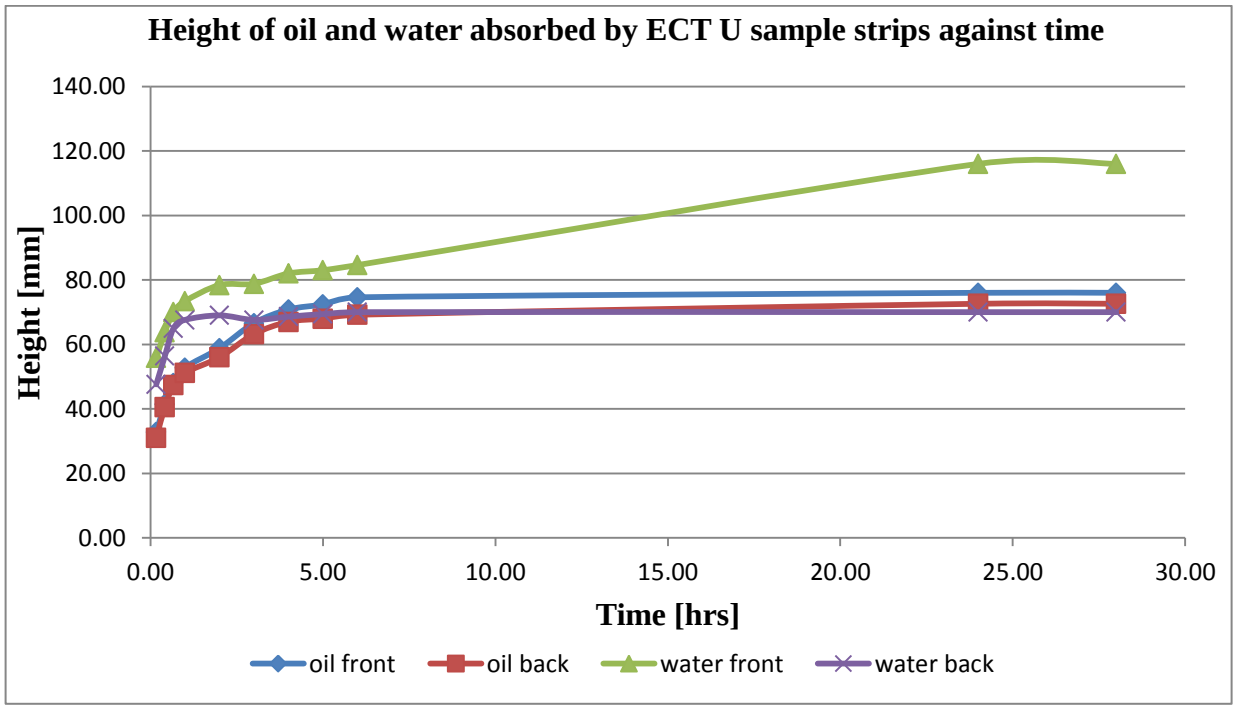


Figure 4.2: Height of oil and water absorbed separately by plane strips of ECT U samples.

When comparing the sorbent behavior between ECT and R15 materials it can be seen that ECT is able to absorb more amount of oil than R15 material (figure 4.1), as it can be seen that after 5 hours oil height for ECT has reached approximately 90 mm and 75 mm for R15. The main reason for this is due to the technologies used to produce these materials because they produce filament fibers with different diameters which lead to different surface area. In ECT material, fibers have got much smaller diameter (range of 2 to 4 μm) compared to R15 fiber diameter (typically range 15-35 μm) [8] therefore ECT has got larger surface area than R15.

ECT U material was tested in both oil and water separately because it exhibit both hydrophilic and hydrophobic properties due to the surface treatment of polypropylene (hydrophobic) fibers. When comparing the behavior of ECT U material in both oil and water, it can be seen that this material is able to absorb huge amount of water compared to oil, as it can be seen after 6 hours height showing water absorb is 84.60 mm while oil absorb is 74.60 mm (figure 4.2). This shows that polypropylene fiber (used in ECT U) was treated with an aim of increasing hydrophilic property. In a dynamic region it can be seen that the height of water absorbed is increasing very quickly compared to oil as it can be seen that after two hours height of water absorbed is 78.40 mm and for oil is 56.00 mm. Moreover, the curve for water absorption is steeper and for oil absorption is gentle (figure 4.2). The reason for this behavior is due to the difference in viscosity of water and oil, oil viscosity is 1.57×10^{-5} m^2/s, 20^oC is greater than that of water which is 1.004×10^{-6} m^2/s, 20^oC [13].

Comparing ECT and ECT U it can be seen that ECT oil capacity is greater than oil capacity of ECT U. This can be verified by the height of oil absorbed, ECT U has 72.60 mm height after 24hrs while ECT has 114.00 mm and also gram oil per gram textile in cut parts is greater in ECT material than in ECT U see figure 4.3 and 4.4 and tables 4.1 and 4.2. This is due to fact that polypropylene fibers used in ECT materials have only one property (hydrophobic) while the polypropylene fibers used in ECT U materials have two properties (hydrophilic and hydrophobic) since fibers were treated to decrease the hydrophobic property. It can be seen from figure 4.1 and 4.2 that after 24-28 hours all the tested materials have constant curves which means that they have reached their maximum oil capacity.

ECT does not absorb water while absorbing oil. This is due to the fact that surface tension of water is far greater than that one of polypropylene fiber and oil surface tension is less also.

Surface tension of water is 73 mN /m, of polypropylene is 30.1 mN/m and for oil is 20-35 mN/m [10] see chapter 2.5 on page 26 for explanation. The measurements of absorption height were took on front side (smooth surface) and at the back side (rough surface) and it was observed that sorbent rate for both oil and water was a little bit slow at the back side (rough surface).

It is also very interesting to compare the behavior of sorbents by means of gram oil per gram textile as it is shown on tables (4.3 and 4.4) and figures (4.3 and 4.4) below.

Table 4.3: Mass of oil absorbed and gram oil per gram textile for cut strips of R15 and ECT

Parts of cut strips	1	2	3	4	5	6	7
Size of strips [mm]	(30x15)	(30X20)					
Strips	Mass $\bar{y}$ [g] of oil only						
ECT (oil)	0.98	0.90	0.81	0.64	0.33	0.17	0.06
R15 (oil)	0.31	0.22	0.17	0.15	0.10	0.01	
	Oil [g]/textile[g] (SO)						
ECT (oil)	13.22	9.12	8.17	6.47	3.37	1.73	0.57
R15 (oil)	11.71	6.03	4.80	4.21	2.68	0.30	

Table 4.4: Mass of oil and water absorbed separately and gram oil per gram textile cut strips of ECT U

Parts of cut strips	1	2	3	4	5	6	7
Size of strips [mm]	(30x15)	(30X20)					
Strips	Mass $\bar{y}$ [g] of oil and water separately						
ECT U (oil)	0.93	0.85	0.72	0.51	0.19	0.09	
ECT U (water)	0.74	0.71	0.68	0.52	0.29	0.10	0.02
	Oil [g]/textile[g] (SO)						
ECT U (oil)	10.85	10.00	8.41	5.93	2.27	1.10	0.00
ECT U (water)	7.50	7.19	6.88	5.25	2.89	0.98	0.24

Remarks: The x-axis for figure 4.3 and 4.4 come from the labels of figure 3.4 and they are just labels for cut strips so they must be whole numbers. Mean ($\bar{y}$) values were calculated from 5 sample strips. The details for measured mass of cut strips for oil plus textile, water plus textile separately, and dry textile cuts are shown on the appendix tables 8.6-8.9 while table 8.1 shows whole mass of dry strips sorbents and height before insertion into oil. All these were used in sample calculations below. SO refer to Specific content of oil.

Sample Calculation for ECT U in oil

Mass of dry textile MDT [g] (see appendix table 8.1)

Mass of dry cut strips MDCS [g] (see appendix table 8.6-8.9)

Area of cut strip ACS and Area of whole strip AWS [m^2]

Mass of oil plus textile MOT[g] (see appendix table 8.6-8.9)

Mass of oil absorbed MO [g]

Gram oil per gram textile (specific content of oil SO) [1]

a) $MDCS = \frac{MDT \times ACS}{AWS}$

$= \frac{1.0626g \times 20mm}{249mm}$

$= \underline{0.085g}$

b) MO = MOT – MDCS

= 0.94g – 0.085g

= <u>0.85g</u>

c) SO = MO ÷ Mass of dry MDCS

= 0.85g ÷ 0.085g

= <u>10.00</u>

Similar calculations were done for specific content of water and for oil in other sample.

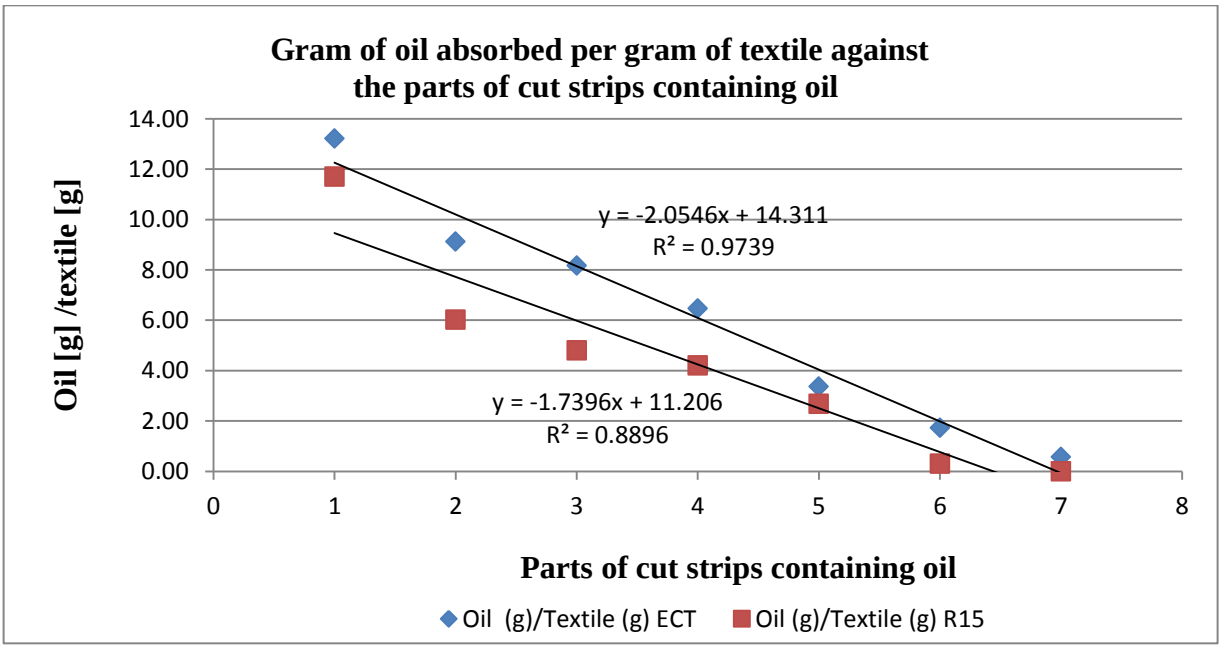


Figure 4.3: Gram oil per gram textile for cut parts of the ECT and R15 strips see figure 3.4

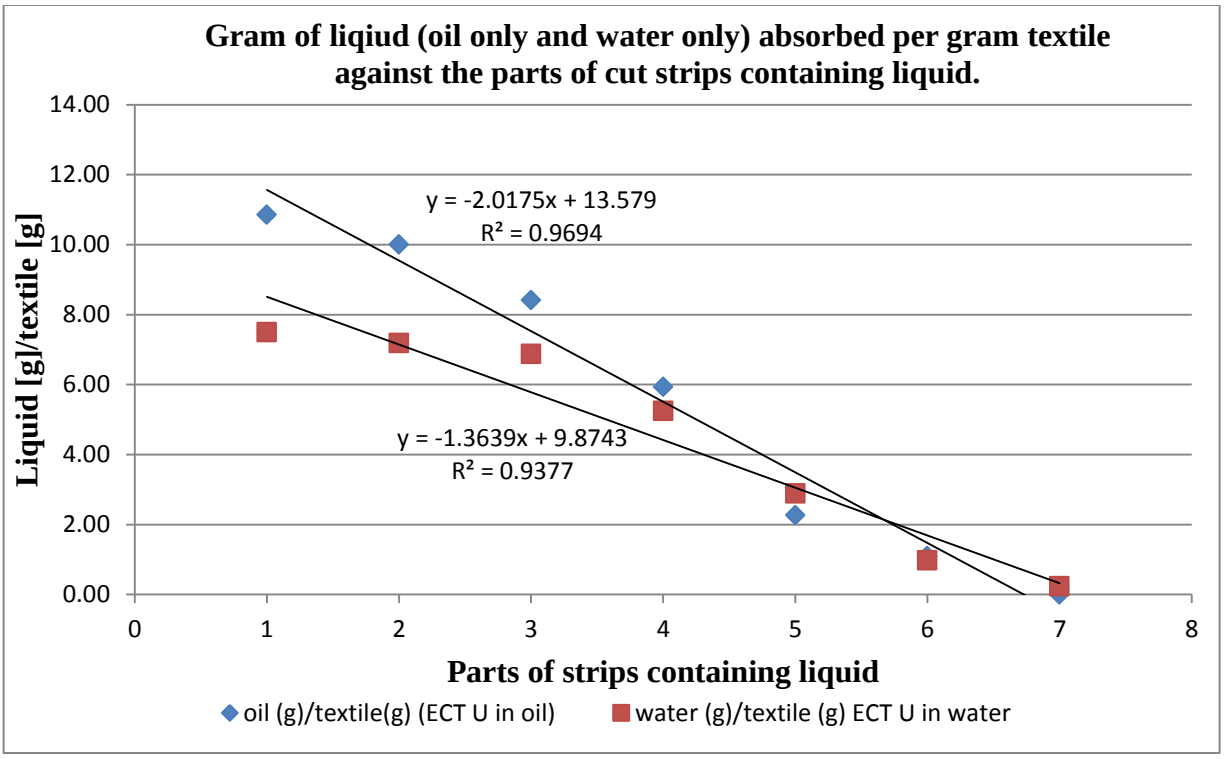


Figure 4.4: Gram (oil only and water only absorbed separately) per gram textile in cut parts of the ECT U strips

In comparing gram oil per gram textile (oil (g)/textile (g)) in parts of cut strips for ECT and R15 it can be seen that there is a great difference in oil (g)/textile (g) from part 1-4 and 6 whereby for ECT is great than for R15, and for parts 5 and 7 it is almost the same (figure 4.3). It has been discussed above that ECT absorbed more oil than R15 due to the increase in height of oil absorb, therefore gram oil per gram textile has verified that.

However, comparison of ECT U tests in oil and water separately, it is observed that there is a great difference in liquids (oil or water) (g)/textile (g) in parts 1-3, for parts 4 and 5 difference is small and for parts 6 and 7 is almost the same (figure 4.4). In contrast, height of water absorbed was greater than height of oil absorbed but gram water per gram textile is less than gram oil per gram textile. Therefore ECT U material can be able to hold more amount of oil than of water. Moreover, it is observed that as number parts of cut strips increase (from 15 mm down part to upper 20mm shown in figure 3.4) oil (g)/textile (g) decreases.

Having discussed the behavior of plane strips in oil absorption it is also very interesting to discuss the behavior of tubular samples made of same materials but different structure and density (g/m^3) in oil clean up.

4.2 Tubular sorbents-results

4.2.1 Results on tests in oil

The tests are described in chapter 3.3.3.1 while the tables and graphs shown on figures below represent the results of those tests.

Table 4.5: Height of oil absorbed for ECT and ECT U to compare the behavior of long and short samples

	Long sample ECT Heavy	Short sample ECT Heavy	Short sample ECT Light	Short sample ECT U Heavy	Short sample ECT U Light
Time [hrs.]	Height $\bar{y}$ [mm]				
0.03	22.00				
0.08	29.00				
0.17	39.00	23.50	27.00	30.00	32.25
0.33	51.00	36.75	39.50	39.25	41.50
0.50	57.00	43.00	44.00	48.00	48.75
0.75	67.00	47.00	47.00	53.25	54.00
1.00	71.00	52.75	53.00	60.00	61.50
2.00	83.00	69.75	66.00	75.00	72.25
3.00	95.00	79.25	75.00	84.75	82.00
4.00	102.00	85.25	80.00	90.00	87.75
5.00	109.00	91.00	85.50	97.50	90.75
6.00	113.00	95.75	88.75	101.00	95.25
7.00	120.00	102.25	94.00	103.25	97.50
24.00	139.00	108.50	105.75	109.75	108.5
25.00	140.00				

Remarks: ($\bar{y}$) is the mean of height values see the appendix table 8.11-8.14 in chapter 8.2. For long samples measurement were took early compare to short sample that is why there are missing value for short samples at the beginning.

The results on a table above were also presented graphically for better analysis see figure 4.5 below.

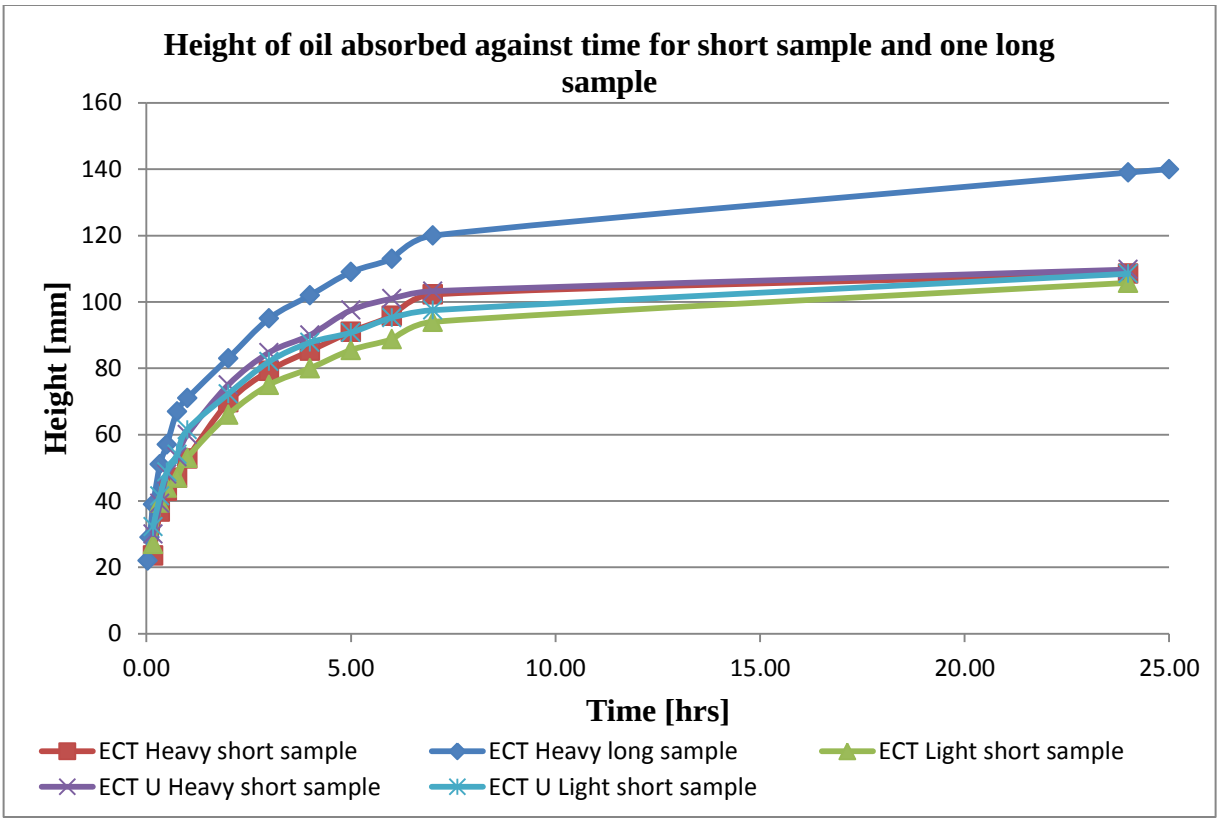


Figure 4.5: Height of oil absorbed (**long** samples are shown in figure 3.10 and **short** ones in figure 3.6)

This first test on tubular sorbents tested how much oil absorbed by different types sorbents by means capillary action only (wicking test). Figure 4.5 shows that ECT long (height 250 mm) sample behaved differently to the short (height 125 mm) as it can be seen that in a long sample oil height reached 139mm over a period of 24 hours while for shorter sample reached 108.5 mm. This means long sample has a higher oil capacity and preferable over short sample because oil would like to move up for short sample but there were no more fibers that it could go through. It can be seen on figure 4.5 that short samples they have approximately the same height over 24 hours. After 24 hours the sample cannot take any more oil. After 7 hours sample begins to take less amount of oil and this is shown by gentle slope of the graph.

ECT and ECT U heavy samples absorbed more oil than ECT and ECT U light because heavy samples have much high density (more number of fibers in a material) which means that the gaps between fibers is much more less, therefore capillary action is more effective for ECT heavy.

ECT U heavy has absorbed more oil compared to ECT heavy while ECT U light has absorbed more oil compared to ECT light but the difference was not significant as it is show (figure 4.5). As to the wicking test heavy sample is better than light sample.

It is also very interesting to compare the behavior of sorbents by means of gram oil per gram textile as it is shown on tables (4.7) and figures (4.6) below.

Table 4.6: Mass of unrolled sample cuts parts (textile & oil) and dry strip

Samples	ECT Light	ECT heavy	ECT U light	ECT U heavy
Parts	Mass [g] textile & oil			
down	61.43	75.72	59.14	68.98
middle	38.70	57.34	43.73	52.18
up	18.00	35.94	24.91	34.03
Mass of dry strip	6.68	9.82	7.39	7.52
Mass of whole dry sample	20.04	29.47	22.16	22.56

Table 4.7: Mass of oil absorbed by each part and gram of oil per gram textile

Samples	ECT Light	ECT heavy	ECT U light	ECT U heavy
Parts	Mass [g] oil only			
down	54.75	65.90	51.75	61.46
middle	32.02	47.51	36.35	44.66
up	11.32	26.12	17.53	26.51
Whole wet sample	98.09	139.53	105.62	132.63
Parts	Oil [g] /textile [g] (SO)			
down	8.19	6.71	7.01	8.17
middle	4.79	4.84	4.92	5.94
up	1.69	2.66	2.37	3.52
Whole sample	**4.89**	**4.73**	**4.77**	**5.88**

Remarks: Both table 4.6 and 4.7 the values measured and calculated are not the mean values but they are from chosen samples. Sample calculations are similar to those in section 4.1. One type of each sample was cut that is why there is no mean for these results. The reason for cutting one sample was due to difficulties during cutting and huge amount of oil lost. SO refer to Specific content of oil see sample calculation on page 55.

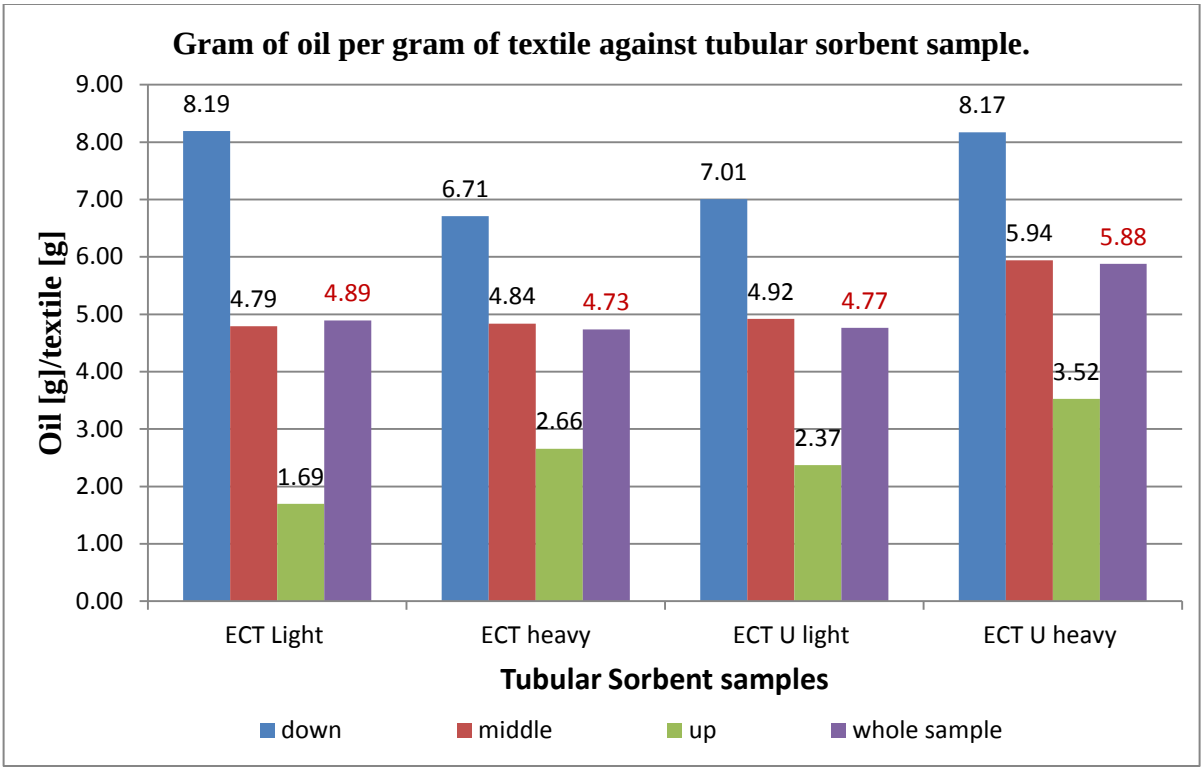


Figure 4.6: Gram oil per gram textile for different sorbents each cut into three parts (the cut parts up, middle and down are shown on figure 3.7)

Down part for all different types of samples contains more gram oil per gram textile while the upper parts contain less gram oil per gram textiles. For the middle parts and whole sample gram oil in gram textile is almost similar except for ECT U which is a bit higher. ECT heavy contains less oil compared to ECT light in a down part sample while the upper part of ECT heavy contains more oil compared to light sample. However, ECT U heavy down and upper parts contains more gram oil per gram textile compared to ECT U light. This is because the heavy samples have higher density (small capillary tubes because of many fibers) than light sample therefore the chances of oil to move up by capillary action are very good in heavy samples than light samples see appendix table 8.10 chapter 8.2. Moreover, ECT U heavy contains more oil than ECT heavy in both down and upper parts while ECT light sample contains more oil in a down part compared to ECT U light. The upper part for ECT U light contains more oil compared to ECT light (figure 4.6). Lastly, oil in whole sample shows that ECT U heavy has more amount of oil 5.88 compared to others where they oil between 4.73 and 4.89.

Therefore, heavy samples seem to be good in absorbing oil by capillary action but this cannot be absolutely true because results were not calculated from mean therefore precision is very low.

Except measuring height of oil absorbed, mass oil absorbed against time was also measured on weight test using balance scale.

4.2.2 Results on weight tests

The tests are described in chapter 3.3.3.2 while the tables and graphs shown on figures below represent the results of those tests.

Table 4.8: Height of oil absorbed by ECT and ECT U long sorbents for weight test

Samples	ECT Light	ECT Heavy	ECT U Light	ECT U Heavy
Time [hrs.]	Height [mm]			
0.03	24.00	22.0	23.0	23.0
0.08	28.00	29.0	30.0	29.0
0.17	40.00	39.0	36.0	37.0
0.33	49.00	51.0	42.0	46.0
0.50	56.00	56.0	50.0	55.0
0.75	61.00	67.0	59.0	60.0
1.00	65.00	71.0	65.0	66.0
2.00	83.00	83.0	79.0	78.0
3.00	89.00	95.0	92.0	91.0
4.00	95.00	102.0	96.0	103.0
5.00	99.00	109.0	98.0	110.0
6.00	101.00	113.0	103.0	112.0
7.00	103.00	120.0	109.0	113.0
24.00	122.00	139.0	130.0	143.0
25.00	122.00	140.0	131.0	143.0

Remark: Measurement from one sample therefore no mean values for table 4.8 to 4.13 see the details on the appendix section 8.3.

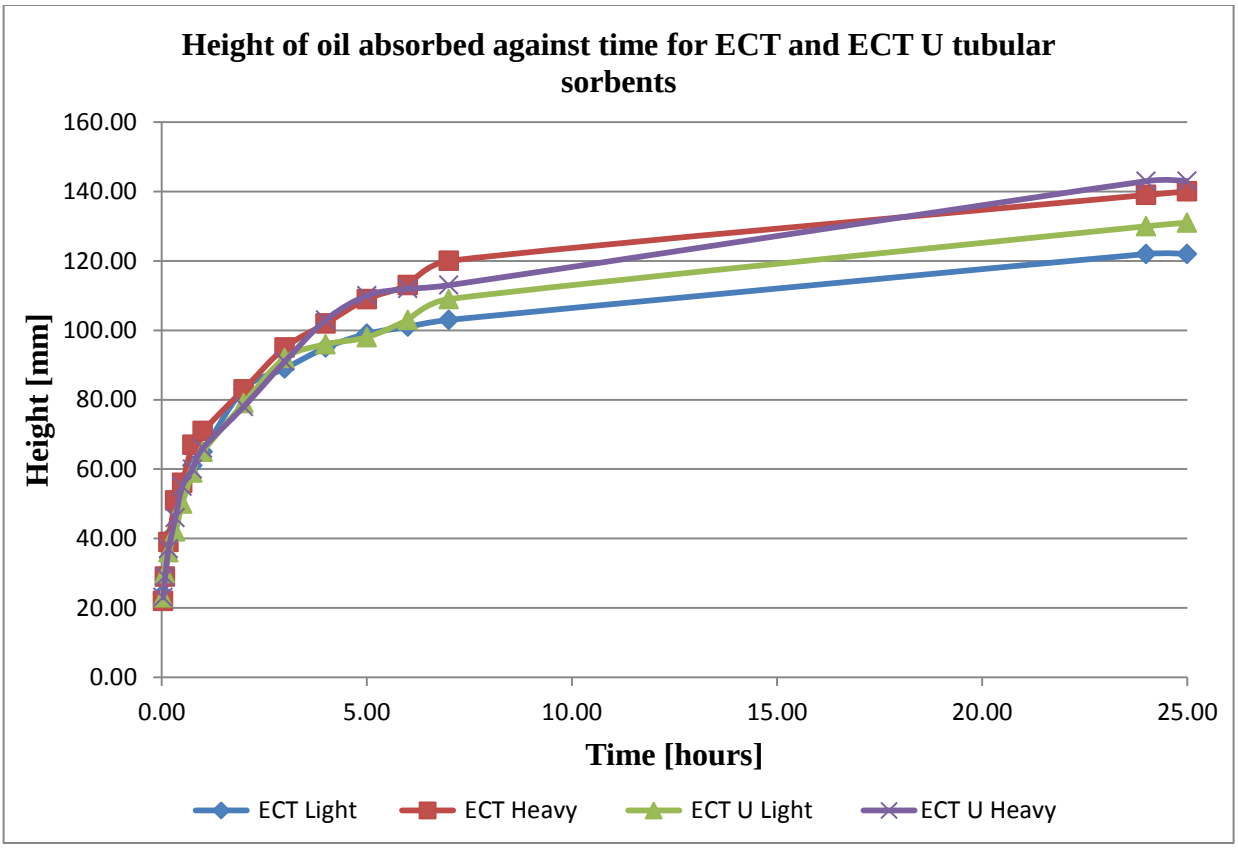


Figure 4.7: Height of oil absorbed by different absorbed for weight test

ECT U heavy shows the better performance which is the results similar to test in oil chapter 4.2.1 figure 4.5 for short sorbents. It is also very interesting to measure the mass of oil left in a container see table 4.9 and figure 4.8 below.

Table 4.9: Mass of oil in a container on a weighing scale

Sample	ECT Light	ECT Heavy	ECT U Light	ECT U Heavy
Time [Hrs.]	Mass [g]			
0.03	336.13	371.56	325.90	336.5
0.08	332.71	361.39	315.82	324.2
0.17	320.78	346.52	307.30	318.7
0.33	313.80	336.95	303.09	304.1
0.50	307.44	330.74	296.86	300.0
0.75	305.41	323.75	291.07	290.9
1.00	301.32	316.14	287.05	287.4
2.00	292.32	307.62	282.09	271.6
3.00	290.45	298.67	276.41	268.9

4.00	287.32	293.88	273.04	263.3
5.00	285.32	290.74	270.62	264.7
6.00	283.93	288.52	271.35	261.2
7.00	282.74	281.69	269.75	256.1
24.00	277.11	277.70	261.99	246.5
25.00	277.07	277.24	261.87	246.1

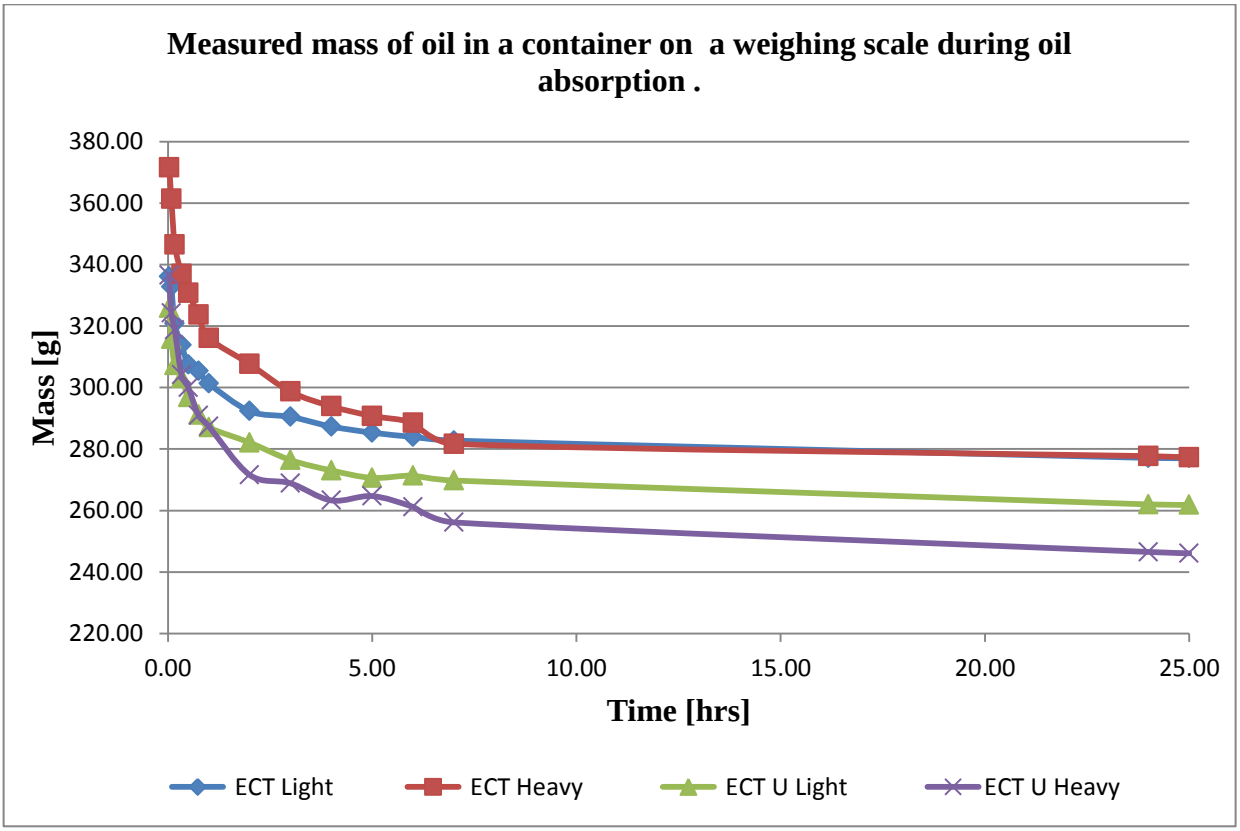


Figure 4.8: Mass of oil in a container on a weighing scale during oil absorption

It is very interesting to calculate the mass of oil left in a sorbent see table 4.10 and figure 4.9 below.

Table 4.10: Mass of oil absorbed by sorbents from container on a weighing scale

Sample	ECT Light	ECT Heavy	ECTU Light	ECTU Heavy
Time [hrs.]	Mass [g] (MOS)			
0.03	36.55	27.92	35.55	35.42
0.08	39.97	38.09	45.63	47.68
0.17	51.90	52.96	54.15	53.19
0.33	58.88	62.53	58.36	67.76

0.50	65.24	68.74	64.59	71.91
0.75	67.27	75.73	70.38	81.00
1.00	71.36	83.34	74.40	84.47
2.00	80.36	91.86	79.36	100.30
3.00	82.23	100.81	85.04	103.03
4.00	85.36	105.60	88.41	108.61
5.00	87.36	108.74	90.83	107.20
6.00	88.75	110.96	90.10	110.70
7.00	89.94	117.79	91.70	115.76
24.00	95.57	121.78	99.46	125.37
25.00	95.61	122.24	99.58	125.81

Remarks: MOS refers to mass of oil in a sorbent see sample calculations below.

Sample calculation for ECT Heavy sorbents

Mass of oil in sorbent MOS [g]

Mass on scale just **after** sample **insertion** MSI [g] see details on chapter 3.3.3.2 table 3.4

Mass on scale MS [g] see details on the appendix table 8.16

$MOS_{(0.03hrs.)} = MSI - MS$

$= 399.48 - 371.56$

$= \underline{27.9\ [g]}$

$MOS_{(0.08hrs.)} = MSI - MS$

$= 399.48 - 361.39$

$= \underline{38.09\ [g]}$

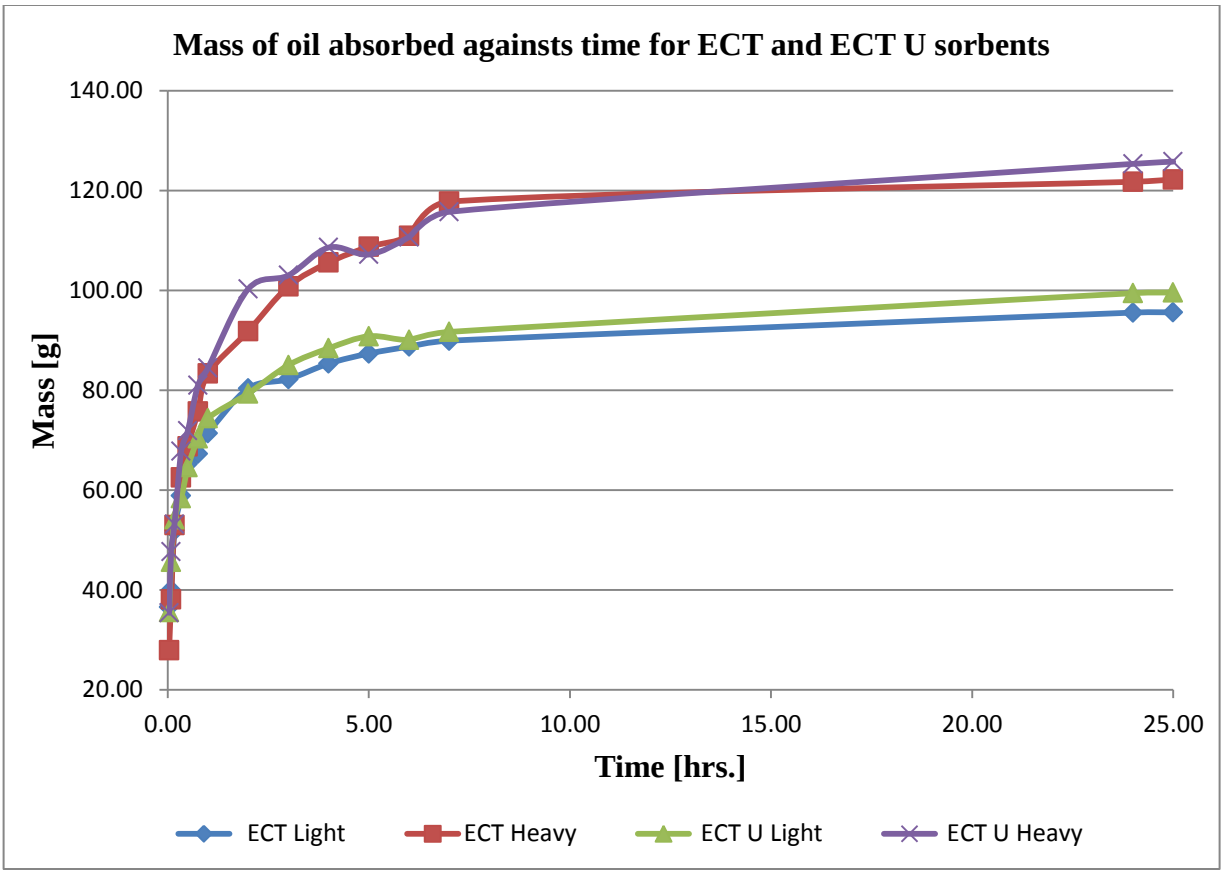


Figure 4.9: Mass of oil absorbed by different samples tested on a weighing scale

It is very interesting also to calculate the gram oil per gram of textile (SO see page 55) for active parts in a sample see table 4.11 and figure 4.10 below.

Table 4.11: Gram oil per gram of textile for active part in a sample

Sample	ECT Heavy	ECT Light	ECT U Heavy	ECT U Light
Time [hrs.]	Oil[g]/textile[g] (SO)			
0.03	3.60	6.21	4.47	5.52
0.08	4.13	6.16	5.19	5.99
0.17	4.68	6.25	4.90	6.27
0.33	4.52	6.10	5.32	6.04
0.50	4.62	6.09	4.92	5.87
0.75	4.41	5.86	5.18	5.61
1.00	4.63	5.91	5.00	5.49
2.00	4.47	5.43	5.17	4.98
3.00	4.37	5.24	4.66	4.69
4.00	4.31	5.14	4.41	4.70
5.00	4.19	5.08	4.11	4.75

6.00	4.14	5.07	4.18	4.51
7.00	4.16	5.05	4.34	4.37
24.00	3.77	4.62	3.80	4.05
25.00	3.76	4.62	3.82	4.03

Remarks: Sample calculations for table 4.11 are similar to those in section 4.1. SO refer to Specific content of oil see sample calculation on page 55.

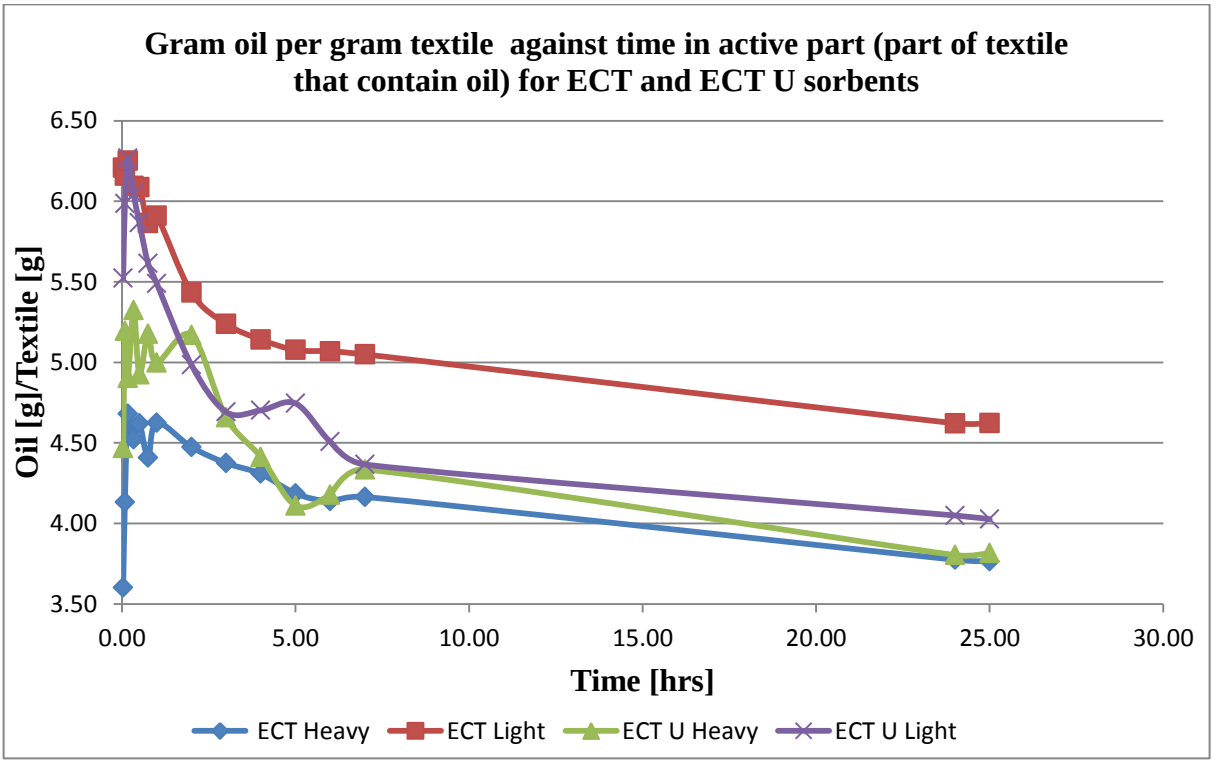


Figure 4.10: Gram oil per gram textile in active part for different sorbents during practical

During the first few hours of the experiment more oil goes into the sample and this gives the information about efficiency of capillary action in an active sample. But when the time goes by the gram oil per gram textile decreases gradually (capillary action becomes less efficient) see figure 4.10 up until it reaches the point where the sample gets full where capillary action stops functioning. Gradually decrease occurs in ECT light sorbents while for other samples (ECT heavy, ECT U light and ECT U heavy) gram oil per gram textile keep on fluctuating up and down for the first hour then after they behave like ECT light (figure 4.10). Figure 4.8 shows that ECT U heavy container is left with less amount of oil which means that sample has wicked large amount of oil while ECT container with a little bit large amount of oil.

Moreover, figure 4.9 and 4.7 show that both heavy samples have wicked large amount of oil after 24 hours compared to light samples. Since heavy samples have high density see table 8.15 in the appendix 8.3 therefore, they contain more oil compared light samples which mean the capillary action is more efficient at the heavy samples.

The gram oil per gram of textile (SO see sample calculations on page 55) was calculated for unrolled cut sample see table 4.13 and figure 4.11 below.

Table 4.12: Mass of unrolled sample cuts parts (textile & oil) and dry strips

	ECT Heavy	ECT Light	ECT U Heavy	ECT U Light
Parts	Mass [g] (textile & oil)			
down	80.45	64.09	88.68	71.06
middle	59.16	45.08	46.96	41.13
up	22.68	13.32	23.41	16.78
Mass[g] dry strip	10.47	7.094	10.43	7.96
Mass of whole dry sample	31.42	21.28	31.29	23.88

Table 4.13: Mass of oil absorbed by each part and gram of oil per gram textile (on weight)

Parts	mass of oil [g]			
down	69.98	56.996	78.25	63.10
middle	48.69	37.986	36.53	33.17
up	12.21	6.226	12.98	8.82
Whole wet sample	130.88	101.21	127.76	105.09
Parts	oil [g] /textile [g] (SO)			
down	6.684	8.034	7.502	7.927
middle	4.650	5.355	3.502	4.167
up	1.166	0.878	1.244	1.108
Whole sample	**4.165**	**4.756**	**4.083**	**4.400**

Remarks: Sample calculations for table 4.13 are similar to those in section 4.1. SO refer to Specific content of oil see sample calculation on page 55.

The down part contains more gram oil per gram textile while the upper part contains less oil. The middle part contains more oil compared upper part but less compared to down part. When looking at down part, ECT and ECT U light contain more oil compared to heavy samples while in the upper part, heavy samples contain more oil compared to light samples even though the difference is not significant.

When looking at the middle part, ECT contains more oil compared to ECT U. For whole sample, ECT heavy, ECT U heavy and light have similar amount of gram oil per gram textile except ECT light which is a little bit higher compared to others (figure 4.11).

The samples that contain more gram oil per gram textile in the upper part are good because the capillary action is more efficient. Therefore it can be concluded that heavy samples are better than light samples as far as wicking is concerned. This conclusion is far less true because the results are not from mean values. For example ECT U heavy sample shows gram oil per gram textile to be 5.88 in figure 4.6 while in figure 4.11 below is 4.08. Therefore in both chapters 4.2.1 and 4.2.2 gram oil per gram textile give results that are not precisely due to absence of repetition of measurements. The results from height show that heavy samples are better than light samples. These results are more precisely due to measurement repetition which was done in chapter 4.2.1 and again they are in agreement to non-repetition height results in chapter 4.2.2. Therefore generally heavy short and long samples are better light sample in wicking tests.

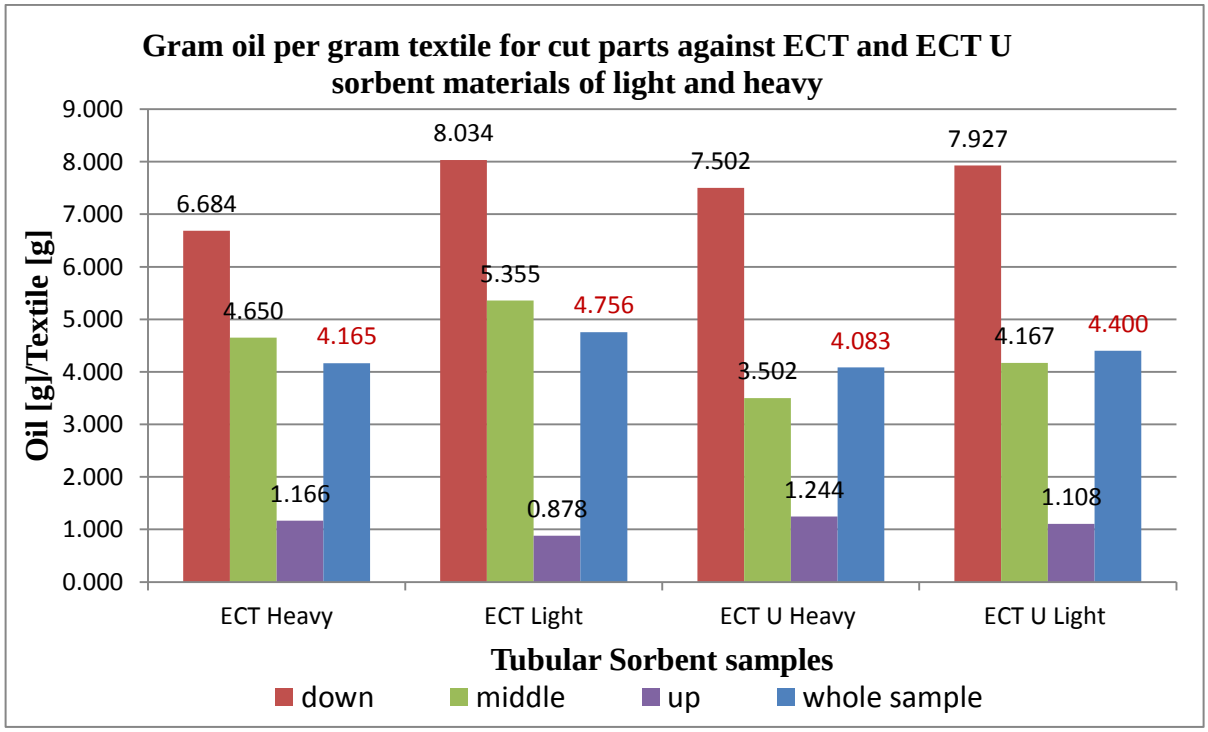


Figure 4.11: Gram oil per gram textile in cut part for different sorbents (cut parts up, middle and down are shown on figure 3.7)

4.2.3 Results in measuring cylinder (volume tests)

This test simulates the nature reality see figure 4.12 below because water and oil are poured into one glass measuring cylinder in which the behavior of sorbents is studied. Studied parameters are described in chapter 3.3.3.3-figure 3.9. The measurements and calculations of all parameters are briefly shown in appendix 8.4 tables 8.19 and 8.20. It has to be noted that unit *ml* were used for practical reasons since the scale on the glass graduated cylinder is in *ml* unit. For calculations especially for checking whether sorbents sunk or not in water unit *mm* was used whereby 2mm is equivalent to 6ml on the graduated scale of measuring cylinder.

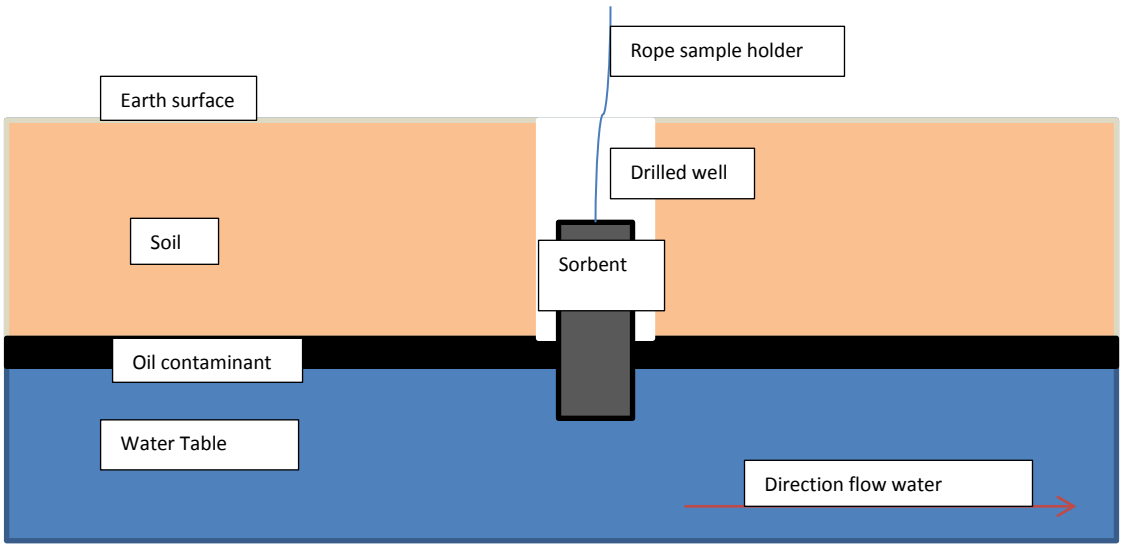


Figure 4.12: Schematic diagram of sorbent in groundwater remediation wells

The graphs of level of sample bottom part are shown on figures 4.13-4.16 below, the tables of these graphs are shown in the appendix 8.4 tables 8.21 and 8.24-8.26. The way of taking the measurements is shown on previous chapter figure 3.9. Graphs on the following figures: 4.13, 4.14, 4.17 and 4.19 were drawn from the data measured in a period of 24 hours and measurements were taken frequently after every 1 or 3 minutes for 1 hour. *These graphs do not display data after 2 hours (120 minutes) because there is small change in values from 2 to 21 hours and from 21 to 24 hours (1440 minutes) the values are almost similar*. Therefore the decision was to draw the graphs with the time range of 0 to 2 hours instead of 24 hours because that is when the samples change their behavior the most. For figure 4.15 it was 168 hours instead of 312 hours. The data for the whole practical is on appendix 8.4 tables 8.21 to 8.25.

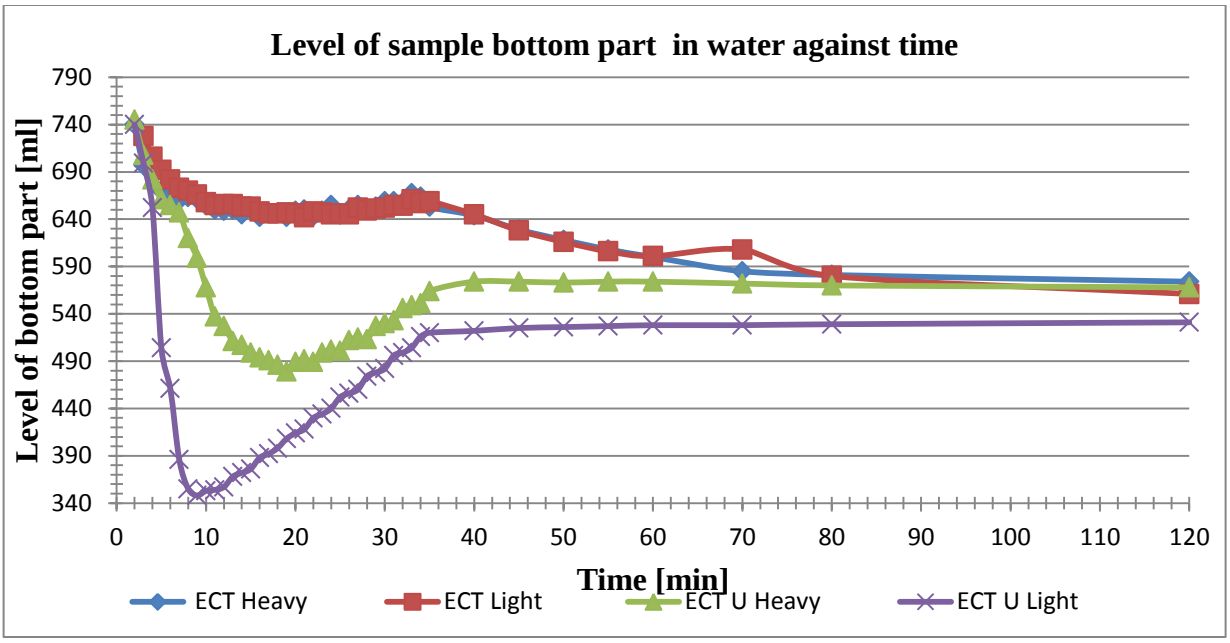


Figure 4.13: Level of sample bottom part for **oil-water standard test 24 hours**

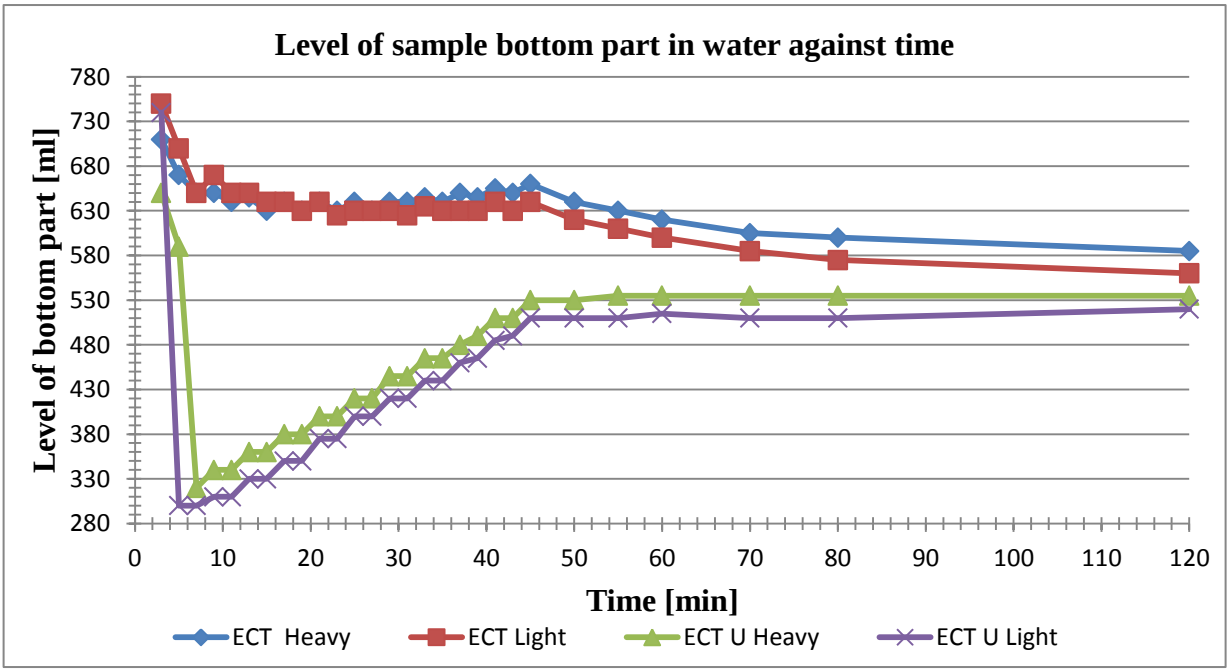


Figure 4.14: Level of sample bottom part for **oil-water compare test 24 hours**

Figure 4.14 data was taken for every 3 minutes that is why there are no points between 3 to 5 minutes. The same experiments were repeated to see the sorbent behavior in a long term (up to 13 days). Tables 8.25 and 8.26 are shown in the appendix 8.4, which were used to draw graphs

below. In these tests readings were taken after 8 hours of sample insertion that is why gaps are seen in figure 4.15 and 4.16.

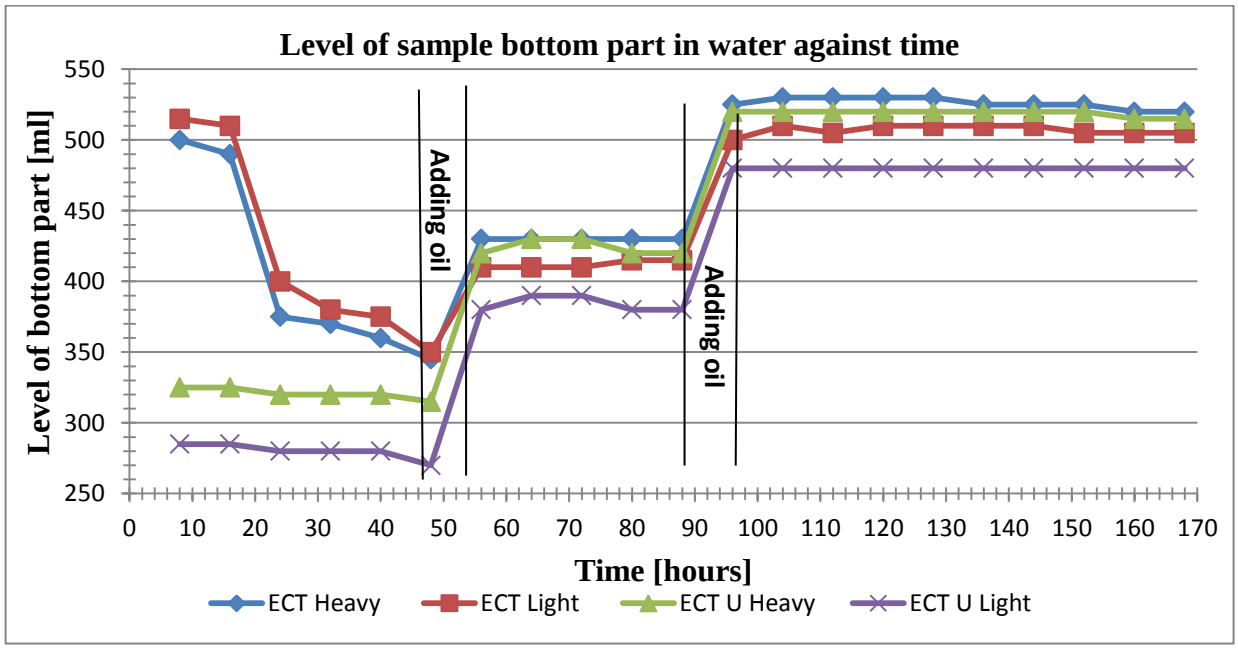


Figure 4.15: Level of sample bottom part for **oil-water long test 13 days**

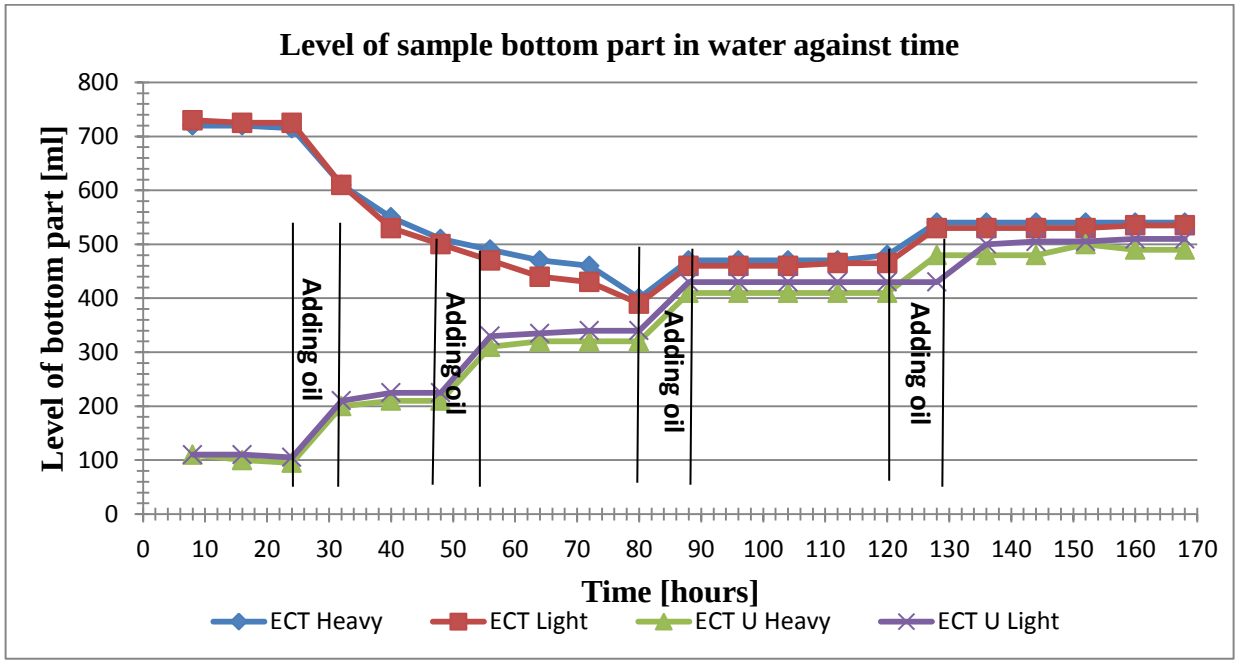


Figure 4.16: Level of sample bottom part for **start water-oil long test 7 days**

Oil-water standard test 24 hours and oil-water compare tests 24 hours behaved very similar (figures 4.13 and 4.14), the ECT heavy and light samples move down slowly through water as time proceeds. ECT U heavy sample move quickly down and reached minimum level after 17 minutes while ECT U light sample also move quickly down and reached minimum level after 8 minutes. ECT U samples have rose up again after reaching the minimum level up until they reach same level which is almost the same to the level reached by ECT samples (figure 4.13 and 4.14). The rising is due to the addition of oil at these time frames in hours: 24, 48, 80 and 120. ECT U samples quickly moved down because they are made up of a material that has got both hydrophilic and hydrophobic properties which means both water and oil are absorbed and wicked at the same time. ECT samples slowly moves down because its material has got only hydrophobic property which means fibers absorb only oil and little amount of water can be absorbed by means of capillary action only.

ECT heavy and light samples have moved down to reach the minimum level of 350 ml after 48 hours for oil-water long test 13 days while same type of samples reached the minimum level of 390ml after 80 hours (figure 4.15 and 4.16). This time difference is due the fact that in oil-water test sample absorbed oil at the beginning of experiment which gave weight on sample and causes a quick move. While for start water then oil long test 7 days, samples stayed long time (one day) in water without absorbing oil for weight support (oil was poured after 24 hours) therefore it moved slowly down. Its downward movement was only due to small water absorption. The samples rose up again to reach the level of approximately 535 ml after reaching the minimum level for both tests (oil-water long test 13 days and start water-oil long tests 7 days) while in the first two tests (24 hours) these samples of ECT moved down only to reach final level of 535 ml.

ECT U samples moved quickly down in both tests whereby approximately 300 ml minimum level was reached for oil- water long test while approximately 100 ml level was reached in the absence of oil for start water-oil long test. Therefore oil caused the sample to float since it is light (figure 4.15 and 4.16).

In start water- oil long test the ECT U samples were about to be submerged under water before oil addition (figure 3.15 a chapter 3). Oil was being absorbed by upper part of the sample only and then oil moved down. After 4 days if was observed that almost half of the sample was empty while there was still more oil left in a cylinder.

In chapter 3 section 3.3.3 figure 3.15 d there are small whitish maps instead of black seen on down part region for unrolled ECT U sample which evidently proves that down part had difficulties in absorbing oil. Therefore, all samples were moved up and down through oil region for 5 minutes to ensure that the whole part of a sample absorbs oil. This moving worked well as there are small whitish maps seen on unrolled sample. ECT samples had better chances of absorbing oil without moving sample up and down because they moved slowly down, so the whole sample becomes black after unrolling (figure 3.12 b). All the samples reached approximately same level (535.3 ml in average) at the end of experiment for all tests.

The oil level [ml] and level sample bottom parts [ml] for the last hours of the experiment before taking out samples were averaged for all sorbents in each types of tests (oil-water standard 24 hours S24, oil-water compare test 24 hours C24, oil-water long test 13 days L13 and start water-oil long test 7 days L7). This information is summarized below on table 4.14 and it helps in deciding whether the sample was sunk or not under water.

Table 4.14: Averages for oil level and sample bottom part at the end of experiments for all measuring cylinder (volume tests)

Tests	Oil level [ml]*	Sample bottom level [ml]*
S24	1187	558
C24	1188	550
L13	1205	514
L7	1174	519
Average	**1188.5**	**535.3**

Remarks: * refers to see figure 3.9.

Measured from graduated cylinder 2mm is equivalent to 6ml

Level of water and oil covering the sorbent = Oil level – Sample bottom level

= 1188.5 – 535.5 = <u>653.2 ml</u>

Length of sample covered by liquids = 653.2 (2//6) = **<u>218 mm</u>**

Whole sample average **length** = **250 mm**

Therefore the part of sample remained uncovered by liquids = 250 – 218 = 32 mm

From these calculations it can be concluded that all samples were not sunk under liquids at the end of experiments see photos in the appendix table 8.31-8.33. This is true even though repetition was only done in oil-water standard test 24 hours and the results for the last 3 tests (C24, L13 and L7) did not deviate much from the first test (S24) that is more precise.

The graphs on figures 4.17-4.19 below show the volume of oil in a cylinder and in sorbents, the tables of these graphs are shown in the appendix 8.4 tables 8.22 and 8.23. All calculated data is shown in appendix table 8.19 and 8.20 for sample calculations of volume of oil in sorbent and in cylinder. The results are only for oil-water standard tests because it was necessary to see all possible behavior of sorbents since repetitions were carried. In other tests especially (L13 and L7) the purpose was to see behavior within long time range whether sorbents can still absorb oil if spend more time in water. Another reason, different oils were used, they make glass cylinder walls very dirty, therefore data of water level was very difficult to take for last three tests so for calculating volume of oil in sorbent and cylinder was impossible.

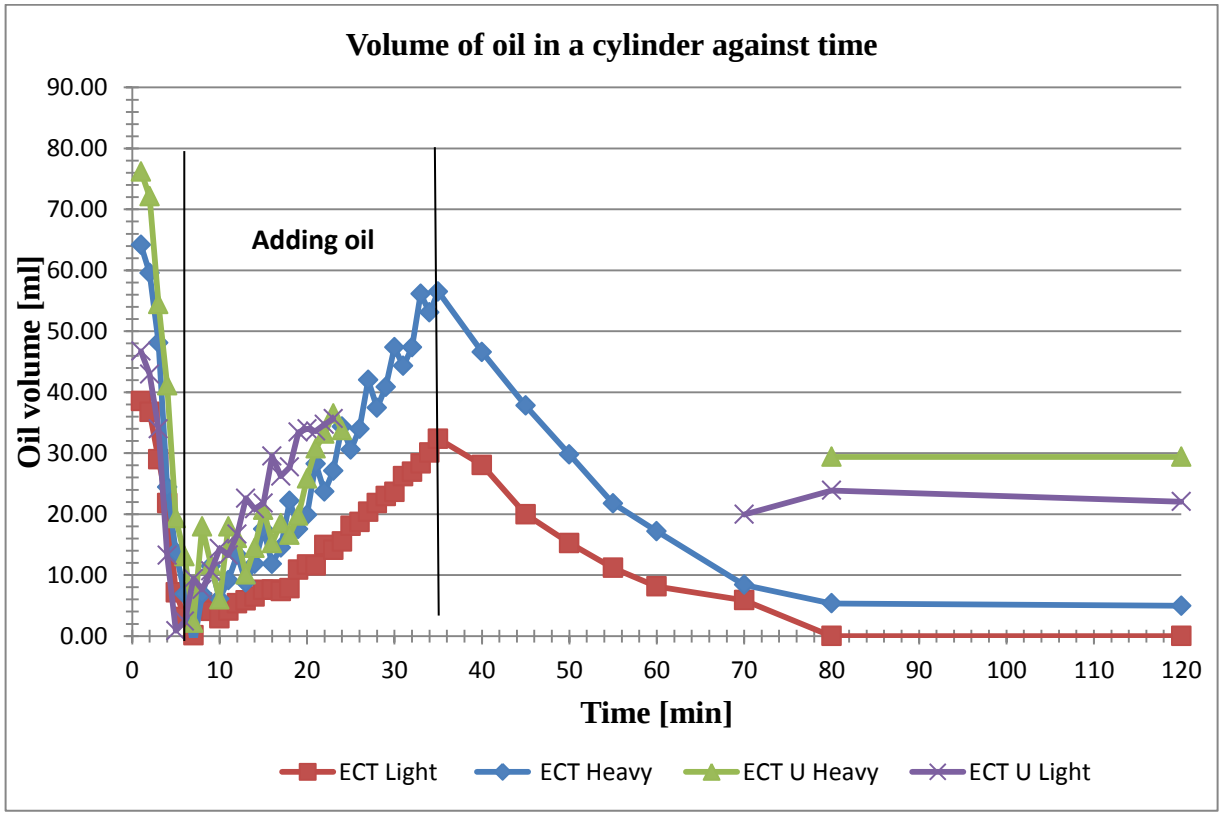


Figure 4.17: Volume of oil in a cylinder (hollow cylinder calculated) for only 120 minutes for **oil-water standard test 24 hours** (see appendix 8.4 table 8.22)

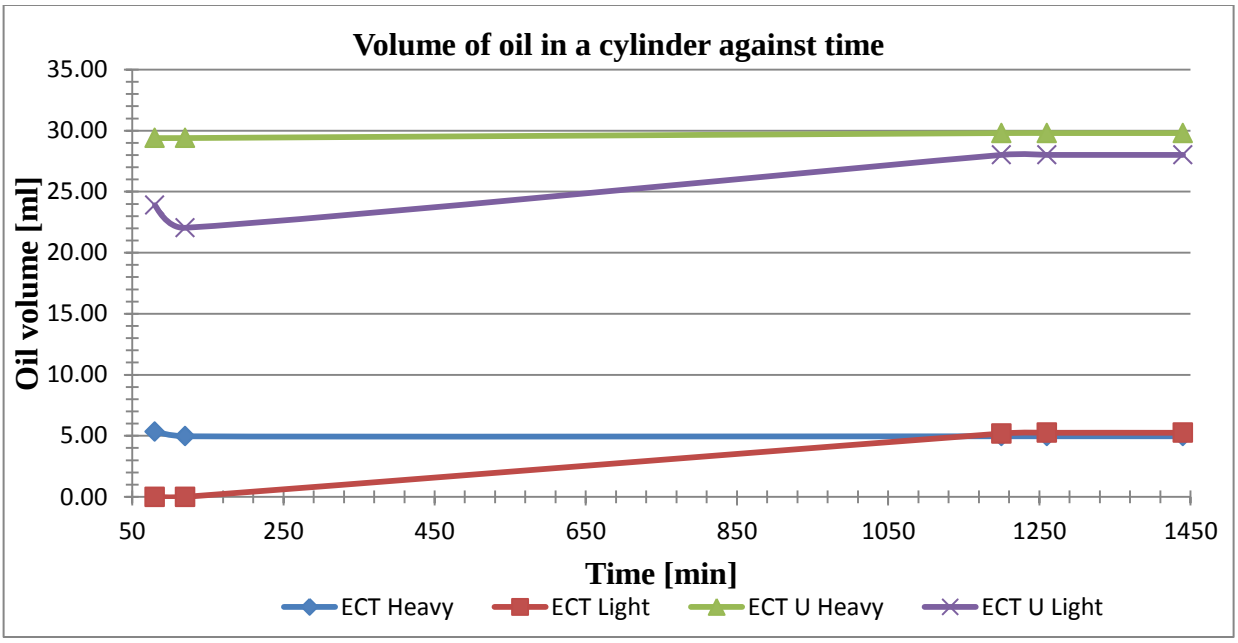


Figure 4.18: Volume of oil in a cylinder (hollow cylinder calculated) from 60 to 1260 minutes for **oil-water standard test 24 hours** (see appendix 8.4 table 8.22)

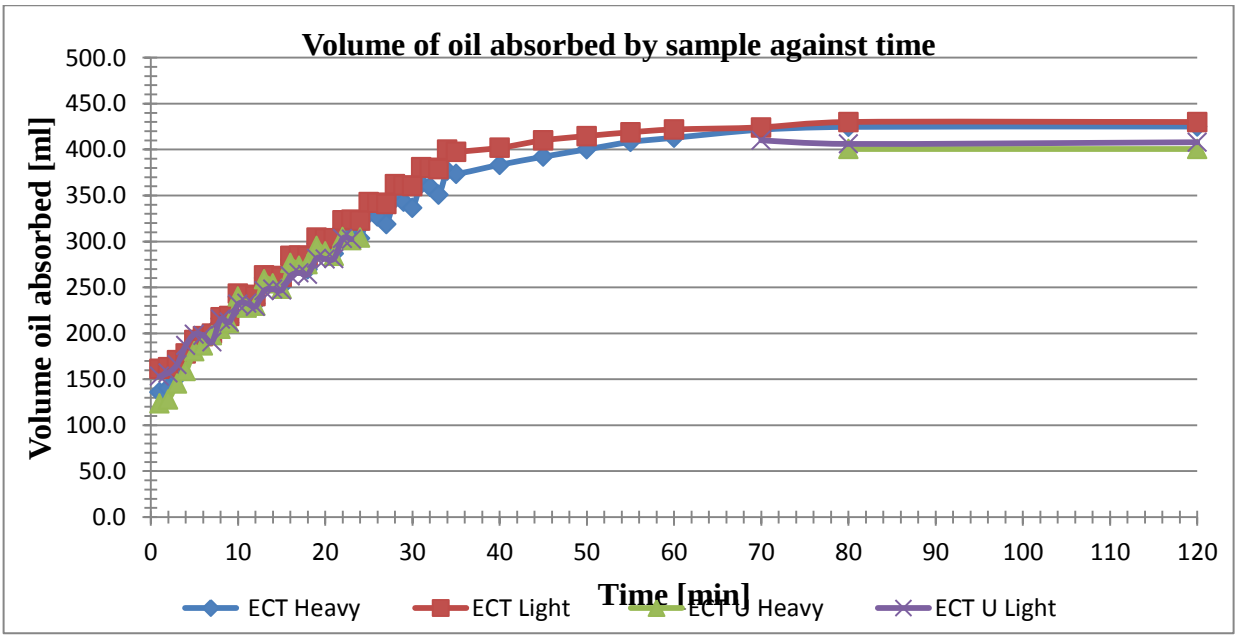


Figure 4.19: Volume of oil absorbed for only 120 minutes for **oil-water standard test 24 hours**

Both figure 4.17 and 4.18 give information about volume of oil in a cylinder during running tests. These graphs are drawn separately because of the importance to clearly show the behavior of the samples for the first 120 minutes and 1440 minutes. If they were drawn from 1 to 1440 minutes it would be very difficult to see sample behavior at early stage of experiment due to time scaling.

It was observed that during the experiment light samples both ECT and ECT U have absorbed almost 430ml of oil after 120 minutes (2 hours). In the next day after 1440 minutes (24 hours) it was observed that a certain volume of oil had move out of the sample even though it was not a huge volume. The slight increase is observed on the graphs (figure 4.18) this evidently shows the poor retention time of light samples. Heavy samples were able to retain the amount oil for a long time 24 hours see figure 4.18 above, it can be seen that graphs are constant from 80 to 1440 minutes. Heavy samples have higher density (see appendix section 8.4 table 8.18) which means more fibers packed together compared to light samples. Therefore, capillary tubes in sample are small enough to hold the liquid.

For both ECT heavy and light samples the amount of oil left in the cylinder after 80 to 120 minutes is between 0 and 5.5 ml that is a minimum volume. The amount of oil left in a cylinder for both ECT U heavy and light samples is between 22 and 30 ml within 80 to 120 minutes (figure 4.17). This information tells that ECT type sample has absorbed more oil in the first two hours compared to ECT U (figure 4.19) (which is the amount of oil absorbed by a sample). This is because ECT has only hydrophobicity property and is subjected to absorb only oil.

In both ECT and ECT U type light samples have less amount of oil left in a cylinder (more amount in a sample) while heavy samples have more amount of oil left in a cylinder which means less oil in sample. This can be seen from figure 4.17 that after eighty (80) minutes cylinder containing heavy sample are left with more oil compared to cylinder containing light samples. This is because light samples have less density (see appendix section 8.4 table 8.18) which means less number of fibers in a sample. Therefore, there are large gaps between fibers which can allow more liquid to be absorbed. These results have good precision because repetition in oil-water standard test that were drawn from mean results.

In the first 5 minutes the graphs (figure 4.17) are decreasing dramatically, this shows how fast 200ml of oil gets absorbed. The zigzag graphs increase is due to addition of oil up to 35minutes for last addition of oil and decrease again up until whole amount of oil goes into sample or some little amount is left when the sample reaches its maximum capacity (full sample). The missing points on graph (figure 4.17) for ECT U sample are due to type of oil used which make wall of the cylinder dirty so level of water was not easy to measure between 22 and 70 minutes.

Graphs of gram oil per gram of textile (SO) for unrolled cut sorbent are shown on figures 4.20-4.23 below. The tables of these graphs are shown in the appendix 8.4 tables 8.27-8.29. The mass dry textiles (whole and cut parts), height of whole sample and cut parts are also shown in the appendix 8.4 table 8.30.

Table 4.15: Gram oil per gram textile (SO) for oil-water standard test 24 hours

	$\bar{y}$ Oil[g]/textile[g]			
Parts	ECT heavy	ECT light	ECT U heavy	ECT U light
Down Part 1	7.0	8.7	6.8	8.6
part 2	6.9	8.2	6.3	8.3
part 3	6.9	8.4	6.3	8.6
Up Part 4	6.0	6.4	5.7	7.6
Whole sample	**6.7**	**7.9**	**6.3**	**8.3**

Remark: For standard test values were calculated from average of 5 samples while for oil-water compare test 24 hours, oil-water long test 13 days and start water-oil long test 7 days values are from one sample, therefore no average see table 3.2. Sample calculations are similar to those in section 4.1.

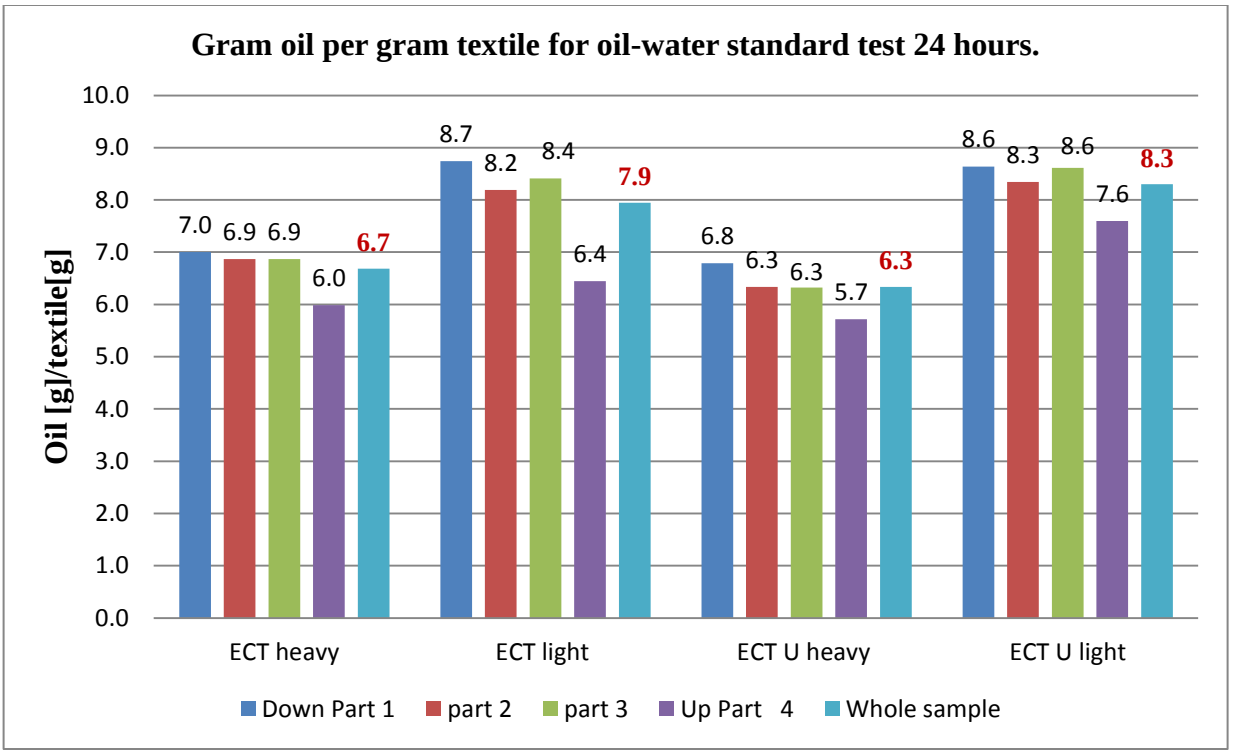


Figure 4.20: Gram oil per gram textile for cut samples for **oil-water standard test 24 hours**

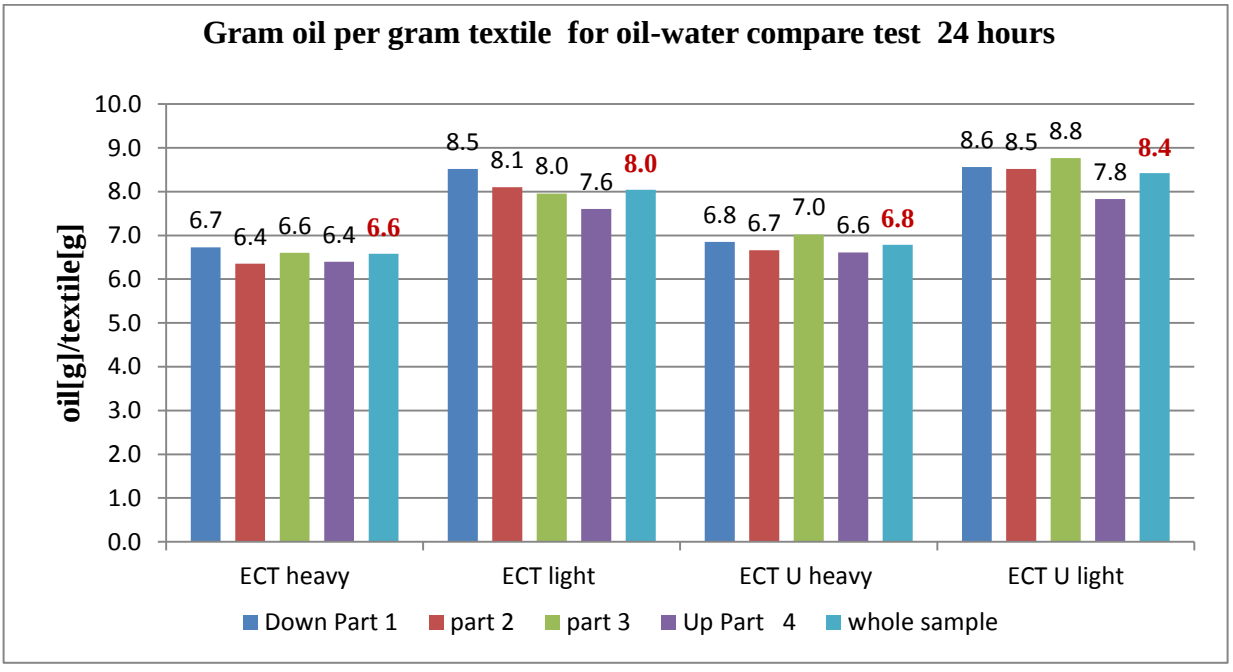


Figure 4.21: Gram oil per gram textile for cut samples for **oil-water compare test 24 hours**

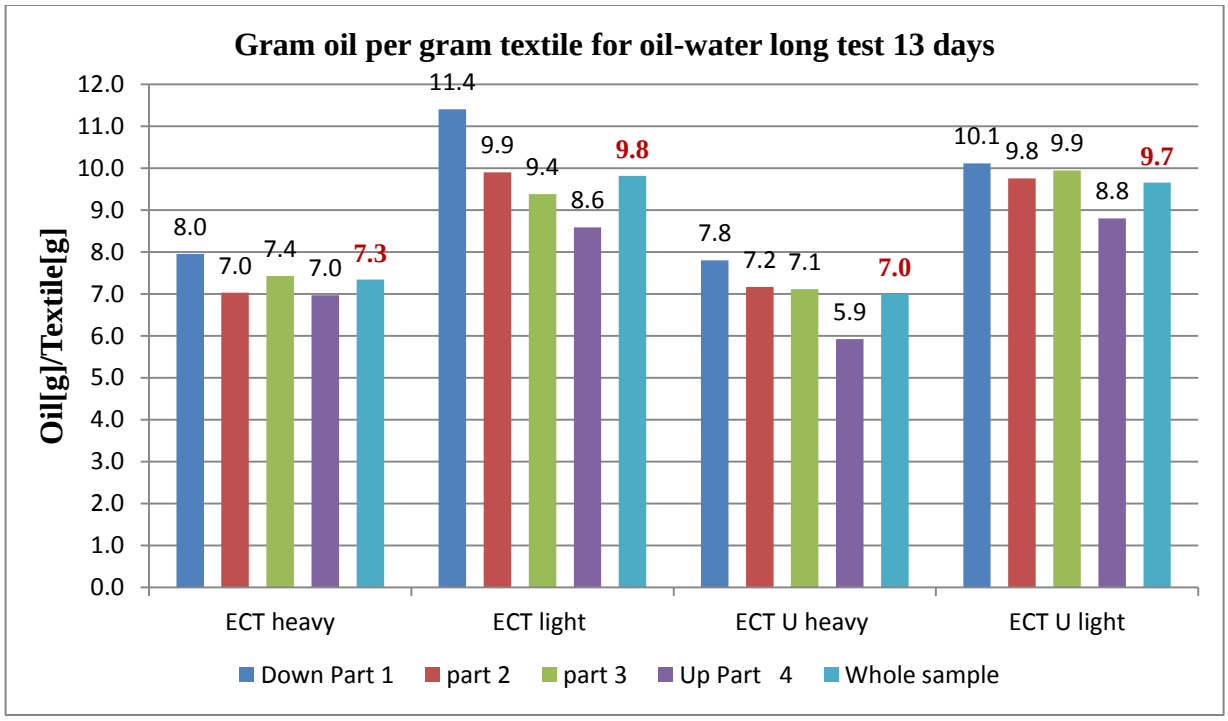


Figure 4.22: Gram oil per gram textile for cut samples for **oil-water long test 13 days**

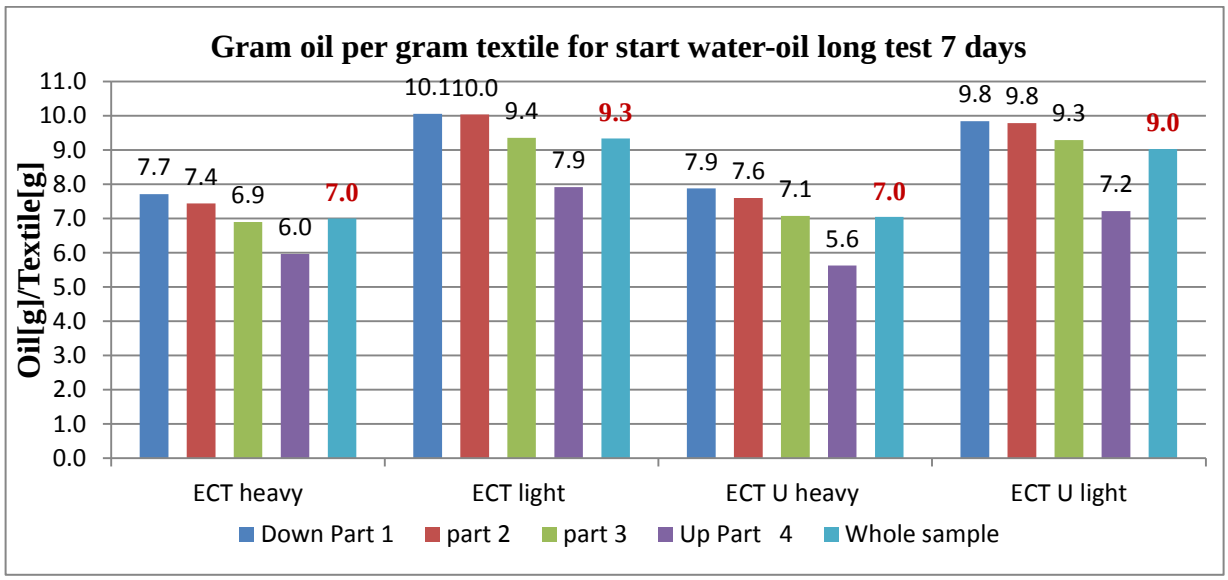


Figure 4.23: Gram oil per gram textile for cut samples for **start water-oil long test 7 days**

The above graphs from figure 4.20 to 4.23 give same information concerning gram oil per gram textile (SO) with slightly different procedures but results are similar. Light samples for both ECT and ECT U types contain high amount of oil compared to heavy samples.

It can be seen that for light samples gram oil per gram textile for all cut parts (from down to up parts) is high compared to heavy samples. Same thing applies to whole sample gram oil per gram textile marked in red color graphs light samples contain more gram oil per gram textile. In contrast to test in oil and weight test, heavy sample absorb high amount of oil than light samples see whole sample graphs marked in red figures 4.6 and 4.11.

This test shows different results from test in oil and weight tests (section 4.2.1 and 4.2.2) because the oil is taken up by both absorption and capillary action in oil-water tests while in oil tests it is by capillary action only. Therefore for test in oil down cut parts have high gram oil per gram textile compared to upper parts but for measuring cylinder test cut parts (down part 1 to up part 4) shows slight difference for individual sample type. In most cases the down part and part 3 contains slightly more oil while part 2 contains slightly less amount of oil. For upper part 4 in all cases have slightly far less amount of oil compared to other parts see figure 4.20 and 4.21 for 24 hours tests. The reason is also based on low density of light samples that is why they absorb huge amount of oil, as explained in this section above. Non-repetition results are in line with repetition results (mean values for more precision) this means results can be statistically trusted.

In long tests (7 and 13 days) see figure 4.22 and 4.23 down part and part 2 have high amount of gram oil per gram textile for all kinds of samples. This is because the samples stayed long time (more than 5 days) in water therefore oil experienced gravitational dragging long time compared to tests for 24 hours.

It is very interesting to calculate the efficiency of samples through measuring the amount of oil that is left in cylinder after sample has been removed see appendix 8.4 photos (after take out sample-rest of oil) on table 8.31-8.33. The results of these efficient calculations are presented on table 4.16 and 4.17, and figures 4.24 and 4.25.

Table 4.16: Rest of oil left in cylinder (after removing the sample) volume and sample efficiency to oil for all measuring cylinder (volume tests)

Tests	Oil-water standard test 24 hours		Oil-water compare test 24 hours		Oil-water long test 13 days		Start water-oil long test 7 days	
	Rest of oil [ml]	Efficiency [%]	Rest of oil [ml]	Efficiency [%]	Rest of oil [ml]	Efficiency [%]	Rest of oil [ml]	Efficiency [%]
ECT Heavy	3.4	99.2	32.0	92.6	118.0	72.6	60	86.0
ECT Light	4.6	98.9	8.0	98.1	45.0	89.5	40	90.7
ECT U Heavy	17.7	95.9	28.0	93.5	70.0	83.7	23	94.7
ECT U Light	15.6	96.4	18.0	95.8	28.0	93.5	20	95.3

Table 4.17: Rest of water left in cylinder and sample efficiency to water for all measuring cylinder (volume tests)

Tests	Oil-water standard test 24 hours		Oil-water compare test 24 hours		Oil-water long test 13 days		Start water-oil long test 7 days	
	Rest of water [ml]	Efficiency [%]	Rest of water [ml]	Efficiency [%]	Rest of water [ml]	Efficiency [%]	Rest of water [ml]	Efficiency [%]
ECT Heavy	739	1.5	743.0	0.9	660	12.0	680	9.3
ECT Light	714.6	4.7	722.0	3.7	670	10.7	690	8.0
ECT U Heavy	710.0	5.3	710.0	5.3	660	12.0	657	12.4
ECT U Light	708.0	5.6	705.0	6.0	662	11.7	680	9.3

Remark: For standard test values were calculated from average of 5 samples while for compare and other tests two long tests values are from one sample, therefore no average. Same thing applies on table 4.19.

Sample calculations of efficiency for standard test for ECT Heavy

Total volume of oil added = 430 ml (see page 44 bolded sentence)

Efficiency [%] = [(Total volume added – Volume left in cylinder)/ Total volume added]*100%

= [(430 -3.4)/430]*100%

= 99.2%

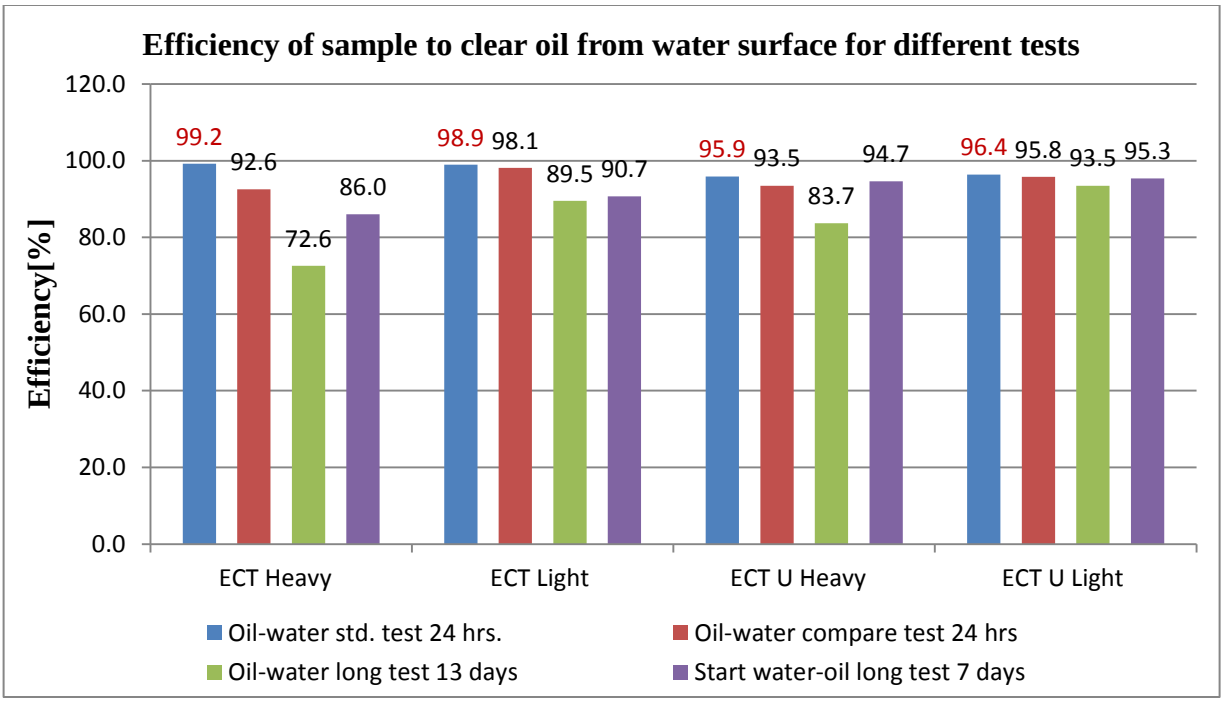


Figure 4.24: Efficiency to oil for all measuring cylinder (volume test)

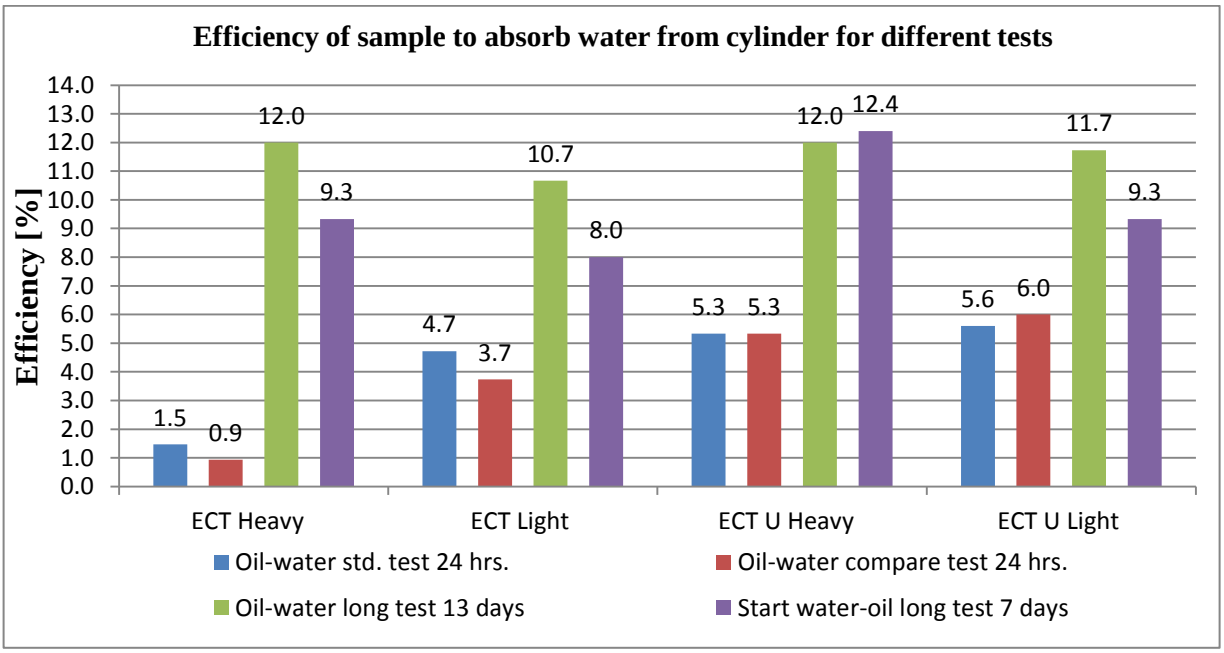


Figure 4.25: Efficiency to water for all measuring cylinder (volume test)

Figure 4.24 shows the sample efficiency to oil by using the volume of oil left in a cylinder after samples are being removed.

The sample efficiency in both oil-water standard and compare 24 hours tests was very high (above 92.6%) and for ECT heavy and light samples is very high, reached 98% and above compared to ECT U samples. In oil-water standard tests 24 hours the efficiency is above 98.9% for both ECT heavy and light samples while for ECT U ranges between 95.9 and 96.4% see red marks on figure 4.24. This is because ECT samples have hydrophobic property with high affinity to oil so they have good efficiency towards oil. These results are precisely because this test had 5 repetitions for each sorbent.

The sample efficiency in the long tests (7 and 13 days) is a bit low for all kinds of tests whereby it ranges between 72.6% and 95.3%. This is due to the fact that if samples stay long time in water they absorb some amount of water as it can be seen on figure 4.25 that sample efficiency to water is higher in the long tests (7 and 13 days) for all samples compared to short tests (24 hours). In generally the time does not affect the sample efficiency to oil by that significant because the efficiency in most tests is above 90%.

Graph shown on figure 4.26 below presents comparison of oil capacity after ending the measurements from test in oil to measuring cylinder (volume test) experiments.

Table 4.18: Comparing mass of oil absorbed for all tubular tested sorbents (sorbent capacity)

Tests	Test in oil	Weight test	Oil-water standard test 24 hours	Oil-water compare test 24 hours	Oil-water long test 13 days	Start water-oil long test 7 days
Samples	Mass [g]					
ECT &R15 heavy	136	133	359	331	333	351
ECT &R15 Light	107	104	377	369	355	360
ECT U &R15 heavy	121	138	375	365	394	403
ECT U &R15 light	109	117	379	375	410	394

Remark: For test in oil, weight test and standard test 24 hours values were calculated from average of 5 samples while for compare test 24 hours and other tests two long tests (7 and 13 days) values are from one sample, therefore no average see overview of samples table 3.2 on chapter 3.2.

In wicking process the sorbents absorb less amount of oil while in both wicking and absorption processes sorbent absorb more amount of oil see figure 4.26. It took approximately **10-24 hours for sorbent to vertically wick a maximum of 140 g** of oil as it can be seen that on figures 4.7-4.9 chapter 4.2.2 the graph stop increasing and figure 4.5 chapter 4.2.1.Graph in figure 4.17 approaches zero volume at 6 minutes and also **took approximately 80 minutes for same type sorbents to absorb and wick approximately 430 ml of oil (390 g)** see figure 4.17 in this chapter 4.2.3. These values give a density of (390/430) 0.91 g/ml which is close to theoretical density of engine oil that is 0.89 g/ml at 20^{o}C [19]. These results are precise because experiments like test in oil and oil-water standard test 24 hours had repetition of samples.

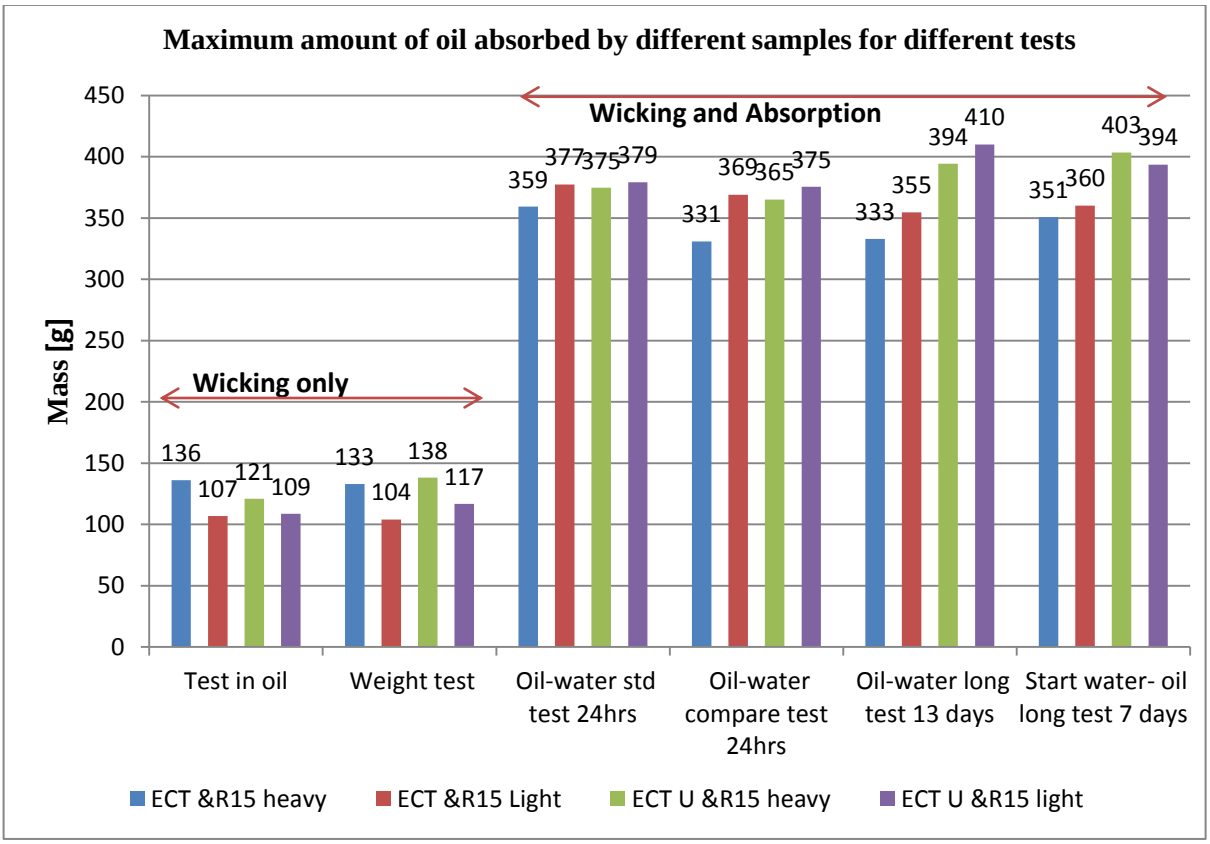


Figure 4.26: Maximum amount of oil absorbed at different types of tests after 24 hours

The measuring cylinder tests (both wicking and absorption operation) shows that samples have contained large amount of oil at the end of experiment. These tests allows samples to absorb huge amount of oil that is almost three times greater than amount in test in oil and weight tests which operate by only wicking (figure 4.26).

Wicking tests shows that heavy samples are much better than light samples (reasons explained in section 4.2.1) while in the wicking and absorption test shows that light samples are slightly better than heavy because the capacity difference is very small. The mass of oil is almost the same for ECT samples in all cylindrical tests while it is different for ECT U samples. The ECT U samples in 24 hours tests exhibit small mass of oil absorbed compared to long tests (4.26). This is because ECT U samples have long time to absorbed water and retain some amount of it which causes mass increase. In generally water have a contribution towards weight even though it is not significant.

It also very interesting to know the amount of oil absorbed by sorbent in volume see table 4.19 below and sample calculations.

Table 4.19: Rest of oil left in cylinder and volume of oil absorbed by a sample for all measuring cylinder (volume tests)

Tests	Oil-water standard test 24 hours		Oil-water compare test 24 hours		Oil-water long test 13 days		Start water-oil long test 7 days	
	Mean Rest of oil [ml]	Oil absorb [ml]	Rest of oil [ml]	Oil absorb [ml]	Rest of oil [ml]	Oil absorb [ml]	Rest of oil [ml]	Oil absorb [ml]
ECT Heavy	3.4	426.6	32.0	398.0	118.0	312.0	60	370
ECT Light	4.6	425.4	8.0	422.0	45.0	385.0	40	390
ECT U Heavy	17.7	412.3	28.0	402.0	70.0	360.0	23	407
ECT U Light	15.6	414.4	18.0	412.0	28.0	402.0	20	410
Mean	10.325	**419.675**	21.5	**408.5**	65.25	**364.75**	35.75	**394.25**

Sample calculations for ECT Heavy for oil-water standard test 24 hours

Amount of oil left in cylinder after sample removed [AOR]

Total amount of oil added [TOA] 430 ml (see page 44 bolded sentence)

Volume of Oil absorbed [VOA]

VOA = TOA - AOR

= 430 – 3.4

= <u>426 ml</u>

The sorbents used in this research work have approximately average of 53 mm diameter, 250 mm height weight: heavy sorbent 53 g and light sorbent 42 g. The sorbent gram oil per gram textile (SO) are as follows: heavy sorbent 6.8 and light sorbent 8.8. These particular sorbents had oil absorption capacity (in grams) of approximately (53*6.8) 360.4 grams for heavy sorbents and (42*8.8) 369.6 grams. The volume of oil for sorbents is approximately 396.8 ml (figure 4.24 and table 4.19 bold numbers). According to Aqua-test remediation wells that are 110-120 mm in diameter 250 mm height (250 g), which means practical sorbents applied in nature can be able to absorb approximately (250*6.8) 1700 g (1.7 kg of oil) or (250*8.8) 2200 g (2.2 kg).

Chapter 5

5. Conclusion

In strip tests (wicking only), it has been shown that sorbent from material ECT absorbs more oil compared to sorbent from material ECT U while both of these melt-blown sorbents absorb more oil than (material used for fixing sorbent structure only) R15. R15 material has good oil absorption efficiency while it was expected to be used for fixing only. ECT U samples have behaved very well (high absorption capacity) in oil medium (in spite of being hydrophilic) compared to water medium.

In test in oil and weight tests of tubular sorbents in containers (wicking only), ECT and ECT U heavy samples absorbed higher amount of oil compared to light samples. Absorption rate is very quickly during the first 7 hours and after these hours absorption rate decreased. After 24 hours samples reached the maximum capacity where wicking stops. Therefore heavy samples have high capacity (chapter 4.2.1-4.2.2).

In measuring cylinder tests (wicking and absorption) results are in contradiction to wicking tests results. According to gram oil per gram textile (SO), light samples have high absorption capacity compared to heavy samples. According to volume of oil absorbed by a sample, light samples have high absorption capacity compared to heavy samples during the first 2 hours but after 24 hours the heavy and light samples have almost the same volume of oil absorbed. This means light samples have poor retention time. Therefore the heavy samples can be regarded as better sorbents over light sorbents due to their better oil retention time (chapter 4.2.3). It can be concluded generally that all four different tubular sorbents have performed their tasks very well, since there were able to absorb the amount of oil (360.4-369.6 g see page 87) that is 6.73 times greater than their original mass (dry sample 53 g). Their efficiency towards absorbing oil is above 90% (figure 4.24). The laboratory sample with 55 mm diameter and height of 250 mm absorbed 396.8 ml of oil within one hour period therefore in nature 120 mm diameter and height 250 mm sample absorbs approximately 2 liters (1.7-2.2kg) within one hour. At the beginning of the experiment 200 ml of oil gets absorbed within 5-7 minutes. This is very fast absorption rate. Samples can stay for long time (days) in wells because time spent in wells does not affect their absorption efficiency (figure 4.26). The SO numbers can be used for making decision during designing sorbents. The sorbents will not sink if used in nature.

Chapter 6

6. Suggestion

The density difference between heavy and light samples should be a more significant (more than 50kg/m^3 or to be more than 10 g mass difference like it was in this experiment). The ECT U samples should be treated in such a way that it can absorb at least 50% oil and 50% water. This will enables the sample to increase water soluble contaminants capacity.

Chapter 7

7 References

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Chapter 8

8 Appendix

8.1 Tests of strips

Table 8.1: Measurements of dry sorption strips (30x250) and height of strips.

	ECT U (water)	ECT (oil)	R15 (oil)	ECT U (oil)
Strips	Mass [g]			
1	1.161	1.256	0.444	1.087
2	1.200	1.234	0.436	1.139
3	1.234	1.202	0.445	1.054
4	1.303	1.201	0.476	1.045
5	1.269	1.224	0.453	0.988
Average	1.233	1.223	0.451	1.063
Height of strips [mm]	250.0	248.0	252.0	249.0

Table 8.2: Measured height for **ECT** sorbents to absorb oil.

Time [hours]	0.2	0.4	0.7	1	2	3	4	5	24
	Height [mm]								
	38	50	58	68	78	85	87	92	115
	39	48	56	65	73	82	83	86	110
	39	50	58	65	77	85	87	89	110
	40	50	60	67	80	85	88	93	120
	40	50	57	66	75	84	86	89	115
Average	39.2	49.6	57.8	66.2	76.6	84.2	86.2	89.8	114.0
STDEV	0.8	0.9	1.5	1.3	2.7	1.3	1.9	2.8	4.2
CV (%)	2.1	1.8	2.6	2.0	3.5	1.5	2.2	3.1	3.7

Table 8.3: Measured height for **R15** sorbents to absorb oil.

Time [hours]	0.1	0.3	0.7	1	2	3	4	5	24
	Height [mm]								
	29	40	50	56	65	69	72	75	80
	30	40	50	58	64	70	73	76	79
	35	45	52	58	65	69	72	74	76
	34	47	53	58	67	70	73	75	78
	34	45	51	57	63	65	67	68	73
Average	32.4	43.4	51.2	57.4	64.8	68.6	71.4	73.6	77.2
STDEV	2.7	3.2	1.3	0.9	1.5	2.1	2.5	3.2	2.8
CV (%)	8.3	7.4	2.5	1.6	2.3	3.0	3.5	4.4	3.6

Table 8.4: Measured height for **ECT U** sorbents to absorb **oil** at the **front** and **back** side.

Time [hours]	0.2	0.4	0.7	1.0	2.0	3.0	4.0	5.0	6.0	24.0
Front Side	Height [mm]									
	30	39	46	50	57	63	65	67	73	75
	32	40	47	51	58	65	68	70	72	76
	35	41	49	54	60	66	70	72	73	76
	35	45	50	55	61	70	76	77	77	77
	32	42	48	54	58	69	75	76	78	76
Average	32.8	41.4	48	52.8	58.8	66.6	70.8	72.4	74.6	76
STDEV	2.17	2.30	1.58	2.17	1.64	2.88	4.66	4.16	2.70	0.71
CV (%)	6.61	5.56	3.29	4.11	2.79	4.33	6.58	5.74	3.62	0.93
Time [hours]	0.3	0.5	0.8	1.0	2.0	3.0	4.0	5.0	6.0	24.0
Back Side	Height [mm]									
	30	41	50	51	53	60	63	64	66	72
	31	40	47	50	58	62	68	69	69	73
	32	39	47	50	55	65	67	68	70	72
	29	43	48	53	59	64	70	71	72	74
	33	40	45	52	55	65	67	68	69	72
Average	31	40.6	47.4	51.2	56	63.2	67	68	69.2	72.6
STDEV	1.58	1.52	1.82	1.30	2.45	2.17	2.55	2.55	2.17	0.89
CV (%)	5.10	3.74	3.83	2.55	4.37	3.43	3.81	3.75	3.13	1.23

Table 8.5: Measured height for **ECT U** sorbents to absorb **colored water** at the **front** and **back** side.

Time [hrs.]	0.2	0.4	0.7	1.0	2.0	3.0	4.0	5.0	6.0	24.0
Front Side	Height [mm]									
	55	62	69	73	78	80	85	86	87	115
	58	65	68	72	75	78	80	81	82	117
	55	64	70	74	79	78	83	84	85	117
	54	62	71	75	80	78	82	83	86	120
	57	66	72	73	80	80	80	81	83	113
Average	55.8	63.8	70	73.4	78.4	78.8	82	83	84.6	116.4
STDEV	1.64	1.79	1.58	1.14	2.07	1.10	2.12	2.12	2.07	2.61
CV (%)	2.94	2.80	2.26	1.55	2.64	1.39	2.59	2.56	2.45	2.24
Time [hrs.]	0.3	0.5	0.8	1.0	2.0	3.0	4.0	5.0	6.0	24.0
Back Side	Height [mm]									
	50	59	65	68	68	68	68	69	69	69
	46	55	64	65	67	67	69	69	69	69

	48	56	64	67	68	70	70	70	71	71
	49	55	67	68	70	68	69	70	71	71
	45	57	65	70	72	65	67	69	70	70
Average	47.6	56.4	65	67.6	69	67.6	68.6	69.4	70	70
STDEV	2.07	1.67	1.22	1.82	2.00	1.82	1.14	0.55	1.00	1.00
CV (%)	4.36	2.97	1.88	2.69	2.90	2.69	1.66	0.79	1.43	1.43

Table 8.6: Measurements of mass for the cut strips (**R15**) **oil with textile** and dry cut strips.

Parts of cut strips	1	2	3	4	5	6
Size of strips [mm]	(30X15)	(30X20)				
Strips	Mass[g]					
1	0.317	0.236	0.205	0.194	0.143	
2	0.321	0.255	0.208	0.194	0.143	
3	0.347	0.229	0.191	0.159	0.120	
4	0.374	0.268	0.227	0.207	0.155	0.047
5	0.346	0.269	0.208	0.177	0.097	
Average (g)	0.341	0.252	0.208	0.186	0.132	0.047
Covariance (CV)	0.000	0.000	0.000	0.000	0.000	
mass of dry cuts [g]	0.027	0.036				

Table 8.7: Measurements of mass for the cut strips (**ECT**) **oil with textile** and dry cut strips.

Parts of cut strips	1	2	3	4	5	6	7
Size of strips [mm]	(30X15)	(30X20)					
Strips	Mass[g]						
1	0.968	0.950	0.941	0.791	0.421	0.279	0.152
2	1.076	0.958	0.811	0.695	0.382	0.219	0.093
3	1.053	1.007	0.884	0.669	0.327	0.219	0.119
4	1.014	0.993	0.887	0.725	0.539	0.323	0.217
5	1.150	1.087	0.999	0.803	0.487	0.309	0.194
Average (g)	1.052	0.999	0.904	0.737	0.431	0.270	0.155
Covariance (CV)	0.004	0.002	0.004	0.003	0.006	0.002	0.002
mass of dry cuts [g]	0.074	0.099					

Table 8.8: Measurements of mass for the cut strips (**ECT U**) **oil with textile** and dry cut strips.

Parts of cut strips	1	2	3	4	5	6	7
Size of strips [mm]	(30X15)	(30X20)					
Strips	Mass[g]						

1	1.075	0.957	0.794	0.502	0.173	0.145	
2	0.896	0.871	0.903	0.679	0.339	0.259	
3	1.006	1.004	0.763	0.590	0.278	0.183	
4	0.939	1.018	0.878	0.661	0.339	0.163	0.091
5	1.012	0.845	0.679	0.526	0.268	0.148	
Average (g)	0.986	0.939	0.803	0.592	0.279	0.179	0.091
Covariance (CV)	0.004	0.005	0.007	0.005	0.004	0.002	
mass of dry cuts [g]	0.064	0.085					

Table 8.9: Measurements of mass for the cut strips (**ECT U**) **water with textile** and dry cut strips.

Parts of cut strips	1	2	3	4	5	6	7
Size of strips [mm]	(30X15)	(30X20)					
Strips	Mass [g]						
1	0.7333	0.7003	0.6786	0.5877	0.3619	0.2164	0.1115
2	0.8051	0.8371	0.7937	0.6165	0.3176	0.1639	0.1276
3	0.8915	0.8321	0.7744	0.6341	0.3927	0.1861	0.1207
4	0.8190	0.8050	0.8013	0.6615	0.4357	0.2191	0.1448
5	0.8202	0.8656	0.8419	0.5823	0.4134	0.1928	0.1090
Average (g)	0.8138	0.8080	0.7780	0.6164	0.3843	0.1957	0.1227
Covariance (CV)	0.0025	0.0033	0.0030	0.0009	0.0017	0.0004	0.0002
mass of dry cuts [g]	0.0740	0.0987					

8.2 Test in oil

Table 8.10: Measurement of mass for dry sorbents, height of sorbent and its diameter.

	Weight $\bar{y}$ [g]	Density $\bar{y}$ [kg/m^3]	Diameter $\bar{y}$ [mm]	Sample height $\bar{y}$ [mm]
ECT heavy	25.9	104.4	52.8	123.0
ECT Light	20.1	72.7	54.0	120.8
ECT U Heavy	25.6	98.4	54.0	120.8
ECT U Light	22.2	80.2	53.5	123.5

Table 8.11: Measured height of oil absorbed by **ECT Heavy** sorbent and calculated average, standard deviation and covariance.

Samples	1	2	3	4			
Time [hrs.]	Height [mm]				Mean[mm]	SD [mm]	CV (%)
0.1	20	21	26	27	23.5	3.51	14.94
0.3	36	37	36	38	36.8	0.96	2.61
0.7	47	48	47	46	47.0	0.82	1.74
1.0	52	54	52	53	52.8	0.96	1.82
2.0	70	70	70	69	69.8	0.50	0.72
3.0	79	78	80	80	79.3	0.96	1.21
4.0	85	86	86	84	85.3	0.96	1.12
5.0	91	90	92	91	91.0	0.82	0.90
6.0	96	95	97	95	95.8	0.96	1.00
7.0	103	101	103	102	102.3	0.96	0.94
24.0	106	110	107	111	108.5	2.38	2.19

Table 8.12: Measured height of oil absorbed by **ECT Light** sorbent and calculated average, standard deviation and covariance.

Samples	1	2	3	4			
Time [hrs.]	Height [mm]				Mean[mm]	SD [mm]	CV (%)
0.1	26	25	29	28	27.0	1.83	6.76
0.3	40	39	39	40	39.5	0.58	1.46
0.7	47	45	48	48	47.0	1.41	3.01
1.0	51	53	53	55	53.0	1.63	3.08
2.0	66	65	65	68	66.0	1.41	2.14
3.0	75	72	76	77	75.0	2.16	2.88
4.0	80	79	80	81	80.0	0.82	1.02
5.0	85	84	86	87	85.5	1.29	1.51
6.0	88	87	90	90	88.8	1.50	1.69
7.0	93	92	96	95	94.0	1.83	1.94
24.0	108	107	103	105	105.8	2.22	2.10

Table 8.13: Measured of height of oil absorbed by **ECT U Heavy** sorbent and calculated average, standard deviation and covariance.

Samples	1	2	3	4			
Time [hrs.]	Height [mm]				Mean[mm]	SD [mm]	CV (%)
0.2	29	28	32	31	30.0	1.826	6.09
0.3	40	39	38	40	39.3	0.957	2.44
0.5	47	48	49	48	48.0	0.816	1.70

0.8	53	54	52	54	53.3	0.957	1.80
1.0	61	60	59	60	60.0	0.816	1.36
2.0	74	75	75	76	75.0	0.816	1.09
3.0	84	85	83	87	84.8	1.708	2.02
4.0	89	90	91	90	90.0	0.816	0.91
5.0	96	99	97	98	97.5	1.291	1.32
6.0	100	101	100	103	101.0	1.414	1.40
7.0	102	103	103	105	103.3	1.258	1.22
24.0	108	111	108	112	109.8	2.062	1.88

Table 8.14: Measured of height of oil absorbed by **ECT U Light** sorbent and calculated average, standard deviation and covariance.

Samples	1	2	3	4			
Time [hrs.]	Height [mm]				Mean[mm]	SD [mm]	CV (%)
0.2	30	33	34	32	32.3	1.708	5.30
0.3	41	42	41	42	41.5	0.577	1.39
0.5	49	50	47	49	48.8	1.258	2.58
0.8	55	56	53	52	54.0	1.826	3.38
1.0	61	62	63	60	61.5	1.291	2.10
2.0	70	74	73	72	72.3	1.708	2.36
3.0	83	84	80	81	82.0	1.826	2.23
4.0	85	89	89	88	87.8	1.893	2.16
5.0	90	92	91	90	90.8	0.957	1.06
6.0	95	98	94	94	95.3	1.893	1.99
7.0	98	100	96	96	97.5	1.915	1.96
24.0	105	109	110	110	108.5	2.380	2.19

8.3 Weight tests

Table 8.15: Measured mass of different dry textile materials, their length and diameter, and calculated mass of oil absorbed.

	Mass dry [g]	Mass wet textile [g]	Mass oil [g]	Length net [mm]	Diameter [mm]	Length sample[mm]	Density [kg/m^3]
ECT & R15 heavy	51.3	184.3	132.9	255	47.0	245.0	120.8
ECT & R15 light	35.6	139.6	104.0	147	48.0	236.0	83.4
ECT U & R15 heavy	51.3	178.6	127.3	254	50.0	246.0	106.2

ECT U & R15 Light	41.2	141.8	100.7	145	49.0	243.0	89.8

Table 8.16: Measured mass of oil in container (MS) and height of oil, calculated mass of oil absorbed for ECT sorbents.

ECT & R15 heavy				ECT & R15 light			
Time [hrs.]	Scale mass [g]	Height [mm]	Mass oil [g]	Time [hrs.]	Scale mass [g]	Height [mm]	Mass oil [g]
0.03	372	22	28	0.03	336	24	37
0.08	361	29	38	0.08	333	28	40
0.17	347	39	53	0.17	321	40	52
0.33	337	51	63	0.33	314	49	59
0.50	331	56	69	0.50	307	56	65
0.75	324	67	76	0.75	305	61	67
1.00	316	71	83	1.00	301	65	71
2.00	308	83	92	2.00	292	83	80
3.00	299	95	101	3.00	290	89	82
4.00	294	102	106	4.00	287	95	85
5.00	291	109	109	5.00	285	99	87
6.00	289	113	111	6.00	284	101	89
7.00	282	120	118	7.00	283	103	90
22.00	279	136	121	24.00	277	122	96
23.00	278	137	121	25.00	277	122	96
24.00	278	139	122				
25.00	277	140	122				

Table 8.17: Measured mass of oil in container and height of oil, calculated mass of oil absorbed for **ECT U** sorbents

ECT U & R15 heavy				ECT U & R15 light			
Time [hrs.]	Scale mass [g]	Height [mm]	Mass Oil [g]	Time [hrs.]	Scale mass [g]	Height [mm]	Mass Oil [g]
0.03	336	23	35	0.03	326	23	36
0.08	324	29	48	0.08	316	30	46
0.17	319	37	53	0.17	307	36	54
0.33	304	46	68	0.33	303	42	58
0.50	300	55	72	0.50	297	50	65
0.75	291	60	81	0.75	291	59	70
1.00	287	66	84	1.00	287	65	74
2.00	272	78	100	2.00	282	79	79
3.00	269	91	103	3.00	276	92	85

4.00	263	103	109	4.00	273	96	88
5.00	265	110	107	5.00	271	98	91
6.00	261	112	111	6.00	271	103	90
7.00	256	113	116	7.00	270	109	92
24.00	247	143	125	24.00	262	130	99
25.00	246	143	126	25.00	262	131	100

8.4 Tests in measuring cylindrical (volume test)

Table 8.18: Measurement of mass for dry sorbents, height of sorbent and its diameter for oil-water standard(S24) and compare (C24) tests 24 hours, oil-water long test 13 days (L13) and start water- oil long test 7 days (L7).

S24	Weight [g]	Density [kg/m3]	Diameter [mm]	Sample height [mm]
ECT heavy	53.8	94.3	53.8	251.4
ECT light	47.5	80.0	55.0	250.0
ECT U heavy	59.2	117.6	50.6	250.4
ECT U light	45.7	80.5	53.8	250.6
C24				
ECT heavy	50.3	98.5	51	250
ECT light	45.9	83.2	53	250
ECT U heavy	53.8	109.6	50	250
ECT U light	44.6	77.0	54	253
L13				
ECT heavy	45.3	92.3	50	250
ECT light	36.1	72.0	50	255
ECT U heavy	56.3	100.1	53	255
ECT U light	42.5	70.1	55	255
L7				
ECT &R15 heavy	50.1	115.4	48	240
ECT light	38.6	80.5	50	244
ECT U heavy	57.3	114.0	50	256
ECT U light	43.6	83.4	51	256

Table 8.19: Measured oil, water and bottom sample level for ECT Heavy and calculated oil volume for oil-water standard test 24 hours.

Parameters	Oil level	Water level	Bottom sample	Oil volume
Time [min]	Volume $\bar{y}$ [ml]			
1	1030	750		280
2	1027	767	740	260
3	1013	803	693	210
4	1003	897	688	107
5	997	937	675	60
6	987	957	666	30
7	967	975	660	-8
8	1007	977	663	30
9	1023	973	656	50
10	1018	992	648	27
11	1028	988	653	40
12	1043	985	650	58
13	1040	1002	644	38
14	1048	997	643	52
15	1063	987	658	77
16	1060	1008	645	52
17	1068	1005	640	63
18	1087	990	652	97
19	1083	1007	645	77
20	1090	1003	644	87
21	1108	985	655	123
22	1107	1003	648	103
23	1115	997	645	118
24	1132	982	652	150
25	1130	997	648	133
26	1138	990	649	148
27	1157	973	655	183
28	1152	988	652	163
29	1162	983	656	178
30	1180	973	664	207
31	1177	983	659	193
32	1183	977	658	207
33	1202	957	658	245
34	1200	968	653	232
35	1208	962	649	247
40	1210	1007	640	203
45	1205	1040	625	165
50	1200	1070	615	130

55	1197	1102	605	95
60	1193	1118	598	75
70	1188	1152	586	37
80	1187	1163	582	23
120	1185	1163	574	22
1200	1187	1165	568	22
1260	1187	1165	568	22
1440	1187	1165	568	22

Remarks: **ȳ** means values are calculated averages.

Table 8.20: Calculated height of sample, volume of sample and cylinder submerged in oil, oil left and oil in sample during test for ECT Heavy for oil-water standard test 24 hours.

Time [min]	Height in oil **ȳ** [mm]	Cylinder. Vol. **ȳ** [ml]	Sample vol. vol. **ȳ** [ml]	Oil left **ȳ** [ml]	Oil addition **ȳ** [ml]	Oil in sample **ȳ** [ml]
1	93	264	200	64	200	136
2	87	245	185	60	200	140
3	70	198	150	48	200	152
4	36	101	76	24	200	176
5	20	57	43	14	200	186
6	10	28	21	7	200	193
7	-3	-8	-6	-2	200	202
8	10	28	21	7	223	216
9	17	47	36	11	223	212
10	9	25	19	6	246	240
11	13	38	29	9	246	237
12	19	55	42	13	246	233
13	13	36	27	9	269	260
14	17	49	37	12	269	257
15	26	72	55	18	269	251
16	17	49	37	12	292	280
17	21	60	45	15	292	277
18	32	91	69	22	292	270
19	26	72	55	18	315	297
20	29	82	62	20	315	295
21	41	116	88	28	315	287
22	34	97	74	24	338	314
23	39	112	84	27	338	311
24	50	141	107	34	338	304
25	44	126	95	31	361	330
26	49	140	106	34	361	327
27	61	173	131	42	361	319
28	54	154	117	37	384	347

29	59	168	127	41	384	343
30	69	195	147	47	384	337
31	64	182	138	44	407	363
32	69	195	147	47	407	360
33	82	231	175	56	407	351
34	77	218	165	53	430	377
35	82	232	176	57	430	373
40	68	192	145	47	430	383
45	55	156	118	38	430	392
50	43	123	93	30	430	400
55	32	90	68	22	430	408
60	25	71	54	17	430	413
70	12	35	26	8	430	422
80	8	22	17	5	430	425
120	7	20	15	5	430	425
1200	7	20	15	5	430	425
1260	7	20	15	5	430	425
1440	7	20	15	5	430	425

Sample calculation for ECT heavy

Volume difference from oil & water level (it is not actual volume of oil left in cylinder):

Volume difference oil & water = oil level – water level

= 1030 -750 = 280ml

Sample Height in oil region = (10mm / 30ml)* volume difference from oil & water level

= (10/30)*280 = 93mm

Cylindrical volume = π *(diameter of cylinder/2)^2* height oil region

= π * (3600/4) *93/1000 = 260ml

Volume of sample in oil region = π *(diameter of sample/2)^2* height oil region

= π * (2724.84/4) *93/1000 = 200ml

Actual volume left in a cylinder:

Volume Oil left in cylinder = Volume of cylinder with oil potion – Volume of sample in oil region

= 264 – 200 = 64 ml

Volume of Oil absorbed by sample = Volume Oil Added – Volume Oil left

= 200 -64 = 136 ml

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Table 8.21: Measured values for bottom part of a sample in a measuring cylinder for **oil-water standard tests 24 hours.**

Samples	ECT Heavy	ECT Light	ECT U Heavy	ECT U Light
Time [min]	Bottom level $\bar{y}$ [ml]			
1				
2	740		745	740
3	697	728	708	699
4	688	706	682	652
5	670	692	661	504
6	666	682	655	461
7	660	673	647	386
8	663	670	620	355
9	662	666	599	348
10	655	658	568	353
11	650	655	537	354
12	649	656	527	357
13	650	656	511	368
14	645	653	507	372
15	650	653	499	376
16	643	648	494	388
17	647	646	491	392
18	646	646	486	398
19	643	647	479	408
20	649	646	489	414
21	650	642	492	418
22	643	648	489	430
23	649	647	499	434
24	655	645	502	440
25	646	646	501	452
26	650	645	512	456
27	655	652	515	460
28	651	649	513	474
29	653	651	527	478
30	659	652	530	482

31	659	655	533	496
32	658	654	546	499
33	668	661	549	504
34	664	657	551	516
35	653	659	564	520
40	644	645	574	522
45	629	628	574	525
50	618	616	573	526
55	608	606	574	527
60	600	601	574	528
70	585	608	572	528
80	581	580	570	529
120	574	561	568	531
1200	568	544	562	525
1260	568	544	562	525
1440	568	544	562	525

Table 8.22: Calculated values for volume of oil in a cylinder **oil-water standard test 24 hours.**

Samples	ECT Heavy	ECT Light	ECT U Heavy	ECT U Light
Time [min]	Volume $\bar{y}$ [ml]			
1	64.15	38.54	76.21	46.73
2	59.57	36.78	72.13	42.98
3	48.11	29.00	54.44	33.99
4	24.44	21.78	41.10	13.24
5	13.75	7.13	19.32	0.86
6	6.87	3.11	13.06	2.40
7	-1.91	0.10	2.18	9.42
8	6.87	5.48	17.96	7.63
9	11.46	4.11	11.70	10.65
10	6.11	2.91	5.99	14.35
11	9.16	4.16	17.96	13.30
12	13.37	5.37	16.06	16.69
13	8.78	5.82	10.07	22.60
14	11.84	6.47	14.43	20.87
15	17.57	7.58	20.69	21.80
16	11.84	7.63	15.24	29.49
17	14.51	7.38	18.51	26.23
18	22.15	7.83	16.60	27.71
19	17.57	10.89	19.73	33.43

20	19.86	11.74	25.86	33.99
21	28.26	11.54	30.76	33.62
22	23.68	14.90	33.21	34.73
23	27.11	14.15	36.47	35.65
24	34.37	15.51	33.75	
25	30.55	18.06		
26	33.99	18.72		
27	42.00	20.37		
28	37.42	21.78		
29	40.86	22.93		
30	47.35	23.63		
31	44.30	26.19		
32	47.35	26.95		
33	56.13	28.30		
34	53.08	30.11		
35	56.52	32.36		
40	46.59	28.05		
45	37.80	19.97		
50	29.79	15.25		
55	21.77	11.19		
60	17.18	8.14		
70	8.40	5.87		19.95
80	5.35	0.00	29.40	23.89
120	4.96	0.00	29.40	22.04
1200	4.96	5.19	29.80	28.02
1260	4.96	5.25	29.80	28.02
1440	4.96	5.25	29.80	28.02

Table 8.23: Calculated values for volume of oil absorbed by sample **oil-water standard test 24 hours.**

Samples	ECT Heavy	ECT Light	ECT U Heavy	ECT U Light
Time [min]	Volume $\bar{y}$[ml]			
1	135.8	161.5	123.8	153.3
2	140.4	163.2	127.9	157.0
3	151.9	171.0	145.6	166.0
4	175.6	178.2	158.9	186.8
5	186.3	192.9	180.7	199.1
6	193.1	196.9	186.9	197.6
7	201.9	199.9	197.8	190.6

8	216.1	217.5	205.0	215.4
9	211.5	218.9	211.3	212.3
10	239.9	243.1	240.0	231.7
11	236.8	241.8	228.0	232.7
12	232.6	240.6	229.9	229.3
13	260.2	263.2	258.9	246.4
14	257.2	262.5	254.6	248.1
15	251.4	261.4	248.3	247.2
16	280.2	284.4	276.8	262.5
17	277.5	284.6	273.5	265.8
18	269.9	284.2	275.4	264.3
19	297.4	304.1	295.3	281.6
20	295.1	303.3	289.1	281.0
21	286.7	303.5	284.2	281.4
22	314.3	323.1	304.8	303.3
23	310.9	323.8	301.5	302.3
24	303.6	322.5	304.3	
25	330.5	342.9		
26	327.0	342.3		
27	319.0	340.6		
28	346.6	362.2		
29	343.1	361.1		
30	336.6	360.4		
31	362.7	380.8		
32	359.6	380.1		
33	350.9	378.7		
34	376.9	399.9		
35	373.5	397.6		
40	383.4	402.0		
45	392.2	410.0		
50	400.2	414.7		
55	408.2	418.8		
60	412.8	421.9		
70	421.6	424.1		410.1
80	424.7	430.0	400.6	406.1
120	425.0	430.0	400.6	408.0
1200	425.0	430.0	400.2	402.0
1260	425.0	424.8	400.2	402.0
1440	425.0	424.8	400.2	402.0

Table 8.24: Measured bottom part of a sample for **oil-water compare test 24 hours.**

Samples	ECT Heavy	ECT light	ECT U Heavy	ECT U light
Time [min]	Bottom level [ml]			
1				
3	710	750	650	740
5	670	700	590	300
7	650	650	320	300
9	650	670	340	310
11	640	650	340	310
13	645	650	360	330
15	630	640	360	330
17	640	640	380	350
19	630	630	380	350
21	640	640	400	375
23	630	625	400	375
25	640	630	420	400
27	630	630	420	400
29	640	630	445	420
31	640	625	445	420
33	645	635	465	440
35	640	630	465	440
37	650	630	480	460
39	645	630	490	465
41	655	640	510	485
43	650	630	510	490
45	660	640	530	510
50	640	620	530	510
55	630	610	535	510
60	620	600	535	515
70	605	585	535	510
80	600	575	535	510
120	585	560	535	520
1200	590	550	540	510
1260	590	550	540	510
1440	590	545	540	510

Table 8.25: Measured bottom part of a sample for **oil-water long test 13 days**.

	ECT Heavy	ECT Light	ECT U Heavy	ECT U Light
Time [hours]	Bottom level [ml]			
8	500	515	325	325
16	490	510	325	325

24	375	400	320	320
32	370	380	320	320
40	360	375	320	320
48	345	350	315	315
56	430	410	420	420
64	430	410	430	430
72	430	410	430	430
80	430	415	420	420
88	430	415	420	420
96	525	500	520	520
104	530	510	520	520
112	530	505	520	520
120	530	510	520	520
128	530	510	520	520
136	525	510	520	520
144	525	510	520	520
152	525	505	520	520
160	520	505	515	515
168	520	505	515	515
312	520	505	515	515

Remarks: Measurements up to 312 hours (13th day) were not included because there were no significant changes on values after 168 hours.

Table 8.26: Measured bottom part of a sample for **start water-oil long test 7 days.**

	ECT Heavy	ECT Light	ECT U Heavy	ECT U Light
Time [hours]	Bottom level [ml]			
8	720	730	110	110
16	720	725	100	110
24	715	725	95	105
32	610	610	200	210
40	550	530	210	225
48	510	500	210	225
56	490	470	310	330
64	470	440	320	335
72	460	430	320	340
80	400	390	320	340
88	470	460	410	430
96	470	460	410	430
104	470	460	410	430
112	470	465	410	430
120	480	465	410	430

128	540	530	480	430
136	540	530	480	500
144	540	530	480	505
152	540	530	500	505
160	540	535	490	510
168	540	535	490	510

Table 8.27: Calculated gram oil per gram textile for **oil-water compare test 24 hours.**

	Oil[g]/textile[g]			
Parts	ECT heavy	ECT light	ECT U heavy	ECT U light
Down Part 1	6.7	8.5	6.8	8.6
part 2	6.4	8.1	6.7	8.5
part 3	6.6	8.0	7.0	8.8
Up Part 4	6.4	7.6	6.6	7.8
Whole sample	6.6	8.0	6.8	8.4

Table 8.28: Calculated gram oil per gram textile for **oil-water long test 13 days.**

	Oil[g]/textile[g]			
	ECT heavy	ECT light	ECT U heavy	ECT U light
Down Part 1	8.0	11.4	7.8	10.1
part 2	7.0	9.9	7.2	9.8
part 3	7.4	9.4	7.1	9.9
Up Part 4	7.0	8.6	5.9	8.8
Whole sample	7.3	9.8	7.0	9.7

Table 8.29: Calculated gram oil per gram textile **–start water-oil long test 7 days.**

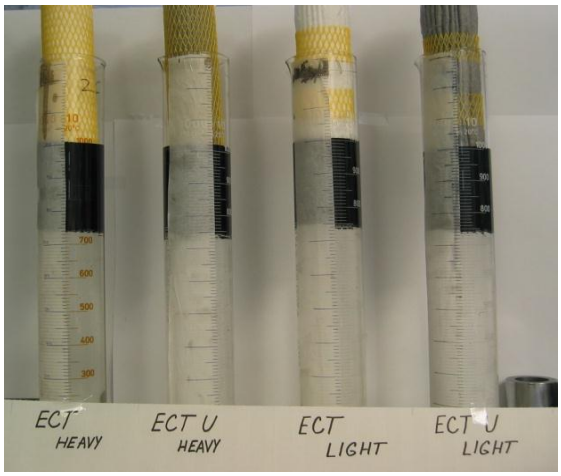
	Oil[g]/Textile[g]			
	ECT heavy	ECT light	ECT U heavy	ECT U light
Down Part 1	7.7	10.1	7.9	9.8
part 2	7.4	10.0	7.6	9.8
part 3	6.9	9.4	7.1	9.3
Up Part 4	6.0	7.9	5.6	7.2
Whole sample	7.0	9.3	7.0	9.0

Table 8.30: Measured dry sample mass, mass of cut samples and calculated gram oil per gram textile **for oil-water standard test 24 hours.**

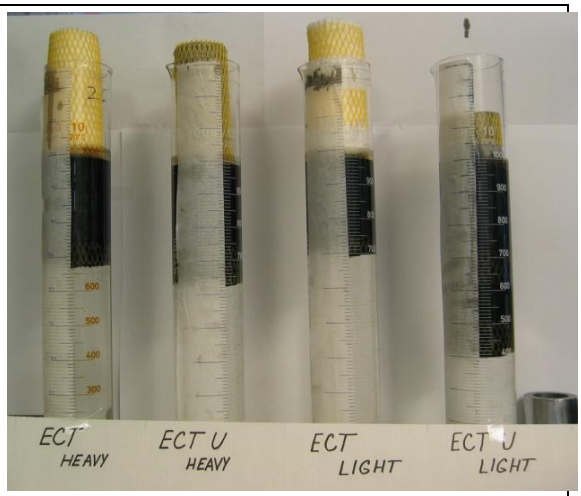
Sample	**ECT Heavy**							
	Weight before test	Weight after test - cutting (oil +textile)						
		Down Part 1	part 2	part 3	Up Part 4	**together**	**Oil in sample**	SO
	g	**g**	**g**	**g**	**g**	**g**	**g**	
1	55	115	110	107	91	**422**	367	
2	50	104	102	100	86	**392**	342	
3	53	101	105	108	97	**411**	358	
4	56	113	109	104	98	**424**	368	
5	54	104	103	109	99	**415**	361	
Average	**54**	**108**	**106**	**106**	**94**	**413**	**359**	**7**
mass dry cuts (g)		**13**						
Height for whole & cut parts ȳ (mm)		**251.36**	**62.84**					
mass of oil (g)		**94**	**92**	**92**	**80**			
oil(g)/text(g)		**7**	**7**	**7**	**6**			**7**
Sample	**ECT Light**							
1	50	116	112	116	93	**437**	387	
2	47	120	111	113	83	**427**	380	
3	45	113	107	115	92	**427**	381	
4	48	112	107	110	91	**419**	371	
5	47	117	109	105	84	**414**	367	
Average	**47**	**116**	**109**	**112**	**88**	**425**	**377**	**8**
Mass dry cuts (g)		**12**						
Height for whole & cut parts ȳ (mm)		**250**	**47.48**					
mass of oil (g)		**104**	**97**	**100**	**76**			
oil(g)/text(g)		**9**	**8**	**8**	**6**			**8**
Sample	**ECT U Heavy**							
1	58	116	111	110	93	**428**	369	
2	58	123	108	107	91	**442**	384	
3	59	117	104	104	104	**426**	368	
4	60	112	110	111	102	**440**	380	

5	61	108	110	109	106	**434**	372	
Average	**59**	**115**	**109**	**108**	**99**	**434**	**375**	**6**
mass dry cuts (g)		**15**						
Height for whole & cut parts ȳ (mm)		**250.4**	**62.6**					
mass of oil (g)		**100**	**94**	**94**	**85**			
Oil[g]/text[g]		**7**	**6**	**6**	**6**			**6**
Sample	**ECT U Light**							
1	45	109	109	113	104	**434**	390	
2	43	107	106	108	98	**418**	375	
3	50	113	112	115	106	**445**	395	
4	47	116	104	103	86	**409**	362	
5	44	106	103	111	97	**418**	374	
Average	**46**	**110**	**107**	**110**	**98**	**425**	**379**	**8**
Mass dry cuts (g)		**11**						
Height for whole & cut parts ȳ (mm)		**250.60**	**62.65**					
mass of oil (g)		**99**	**95**	**98**	**87**			
oil(g)/text(g)		**9**	**8**	**9**	**8**			**8**

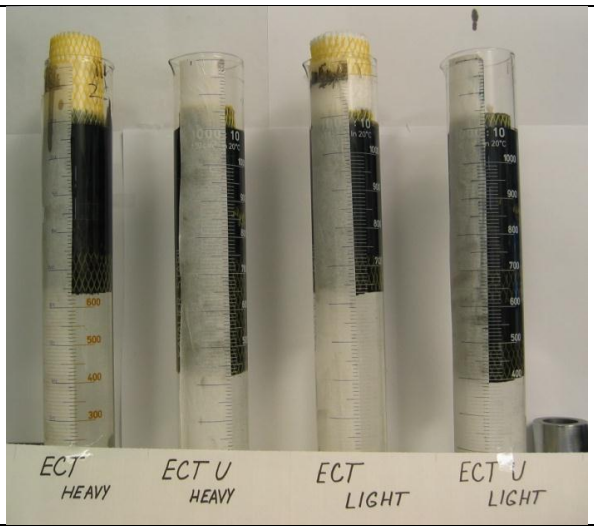
Table 8.31: Oil-water compare test 24 hours



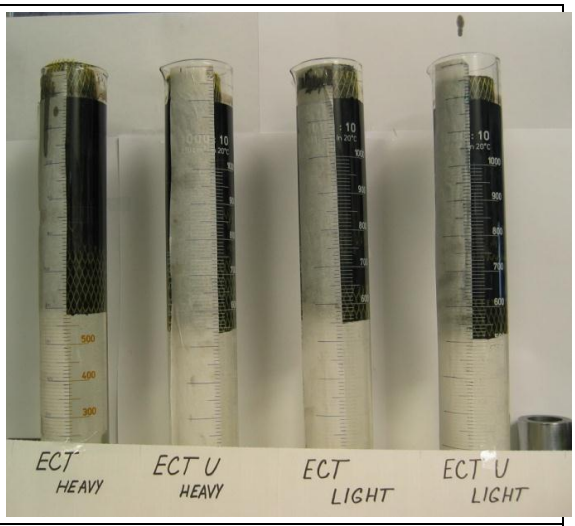
Start of measurement



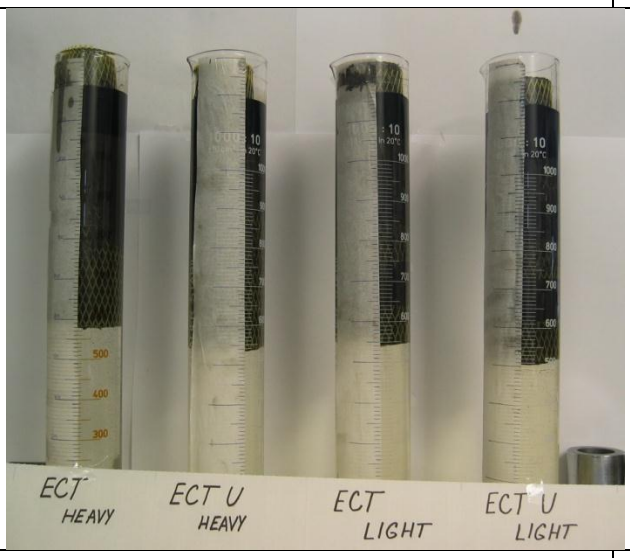
After 7 min - Start of addition



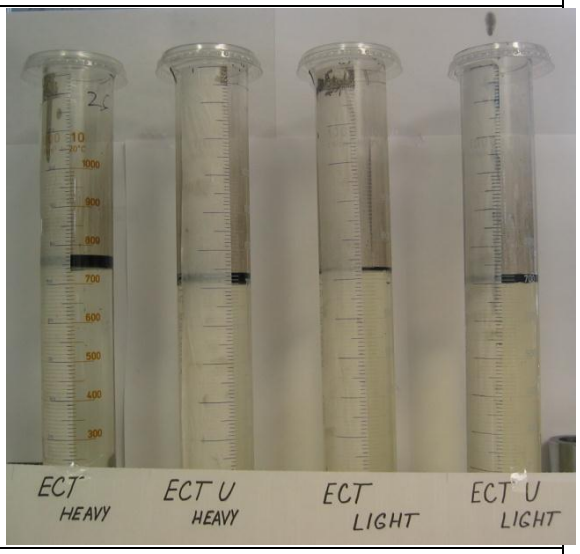
After 35 min – after addition 10x 23ml



After 2 hour



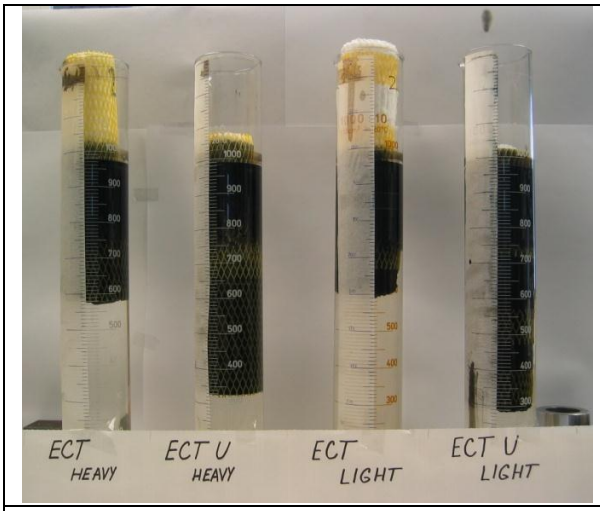
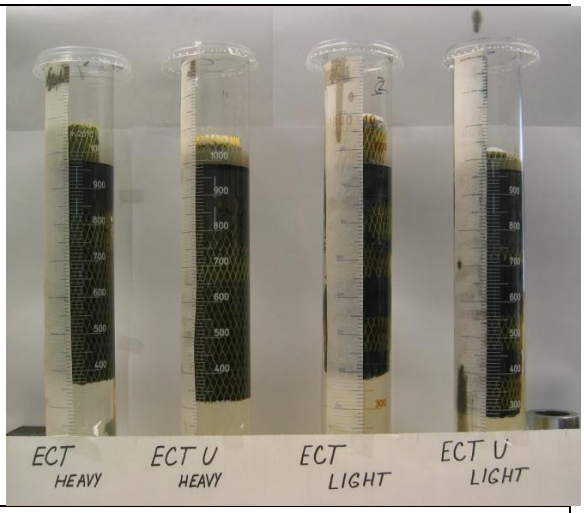
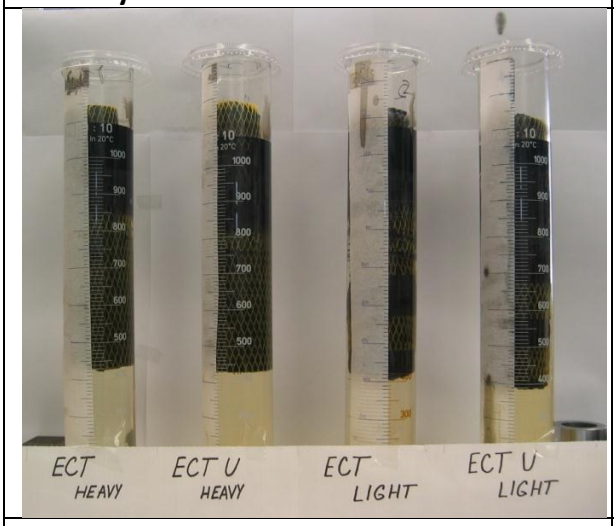
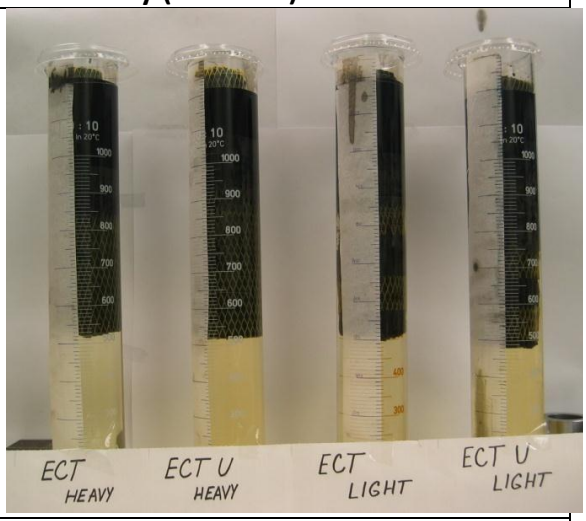
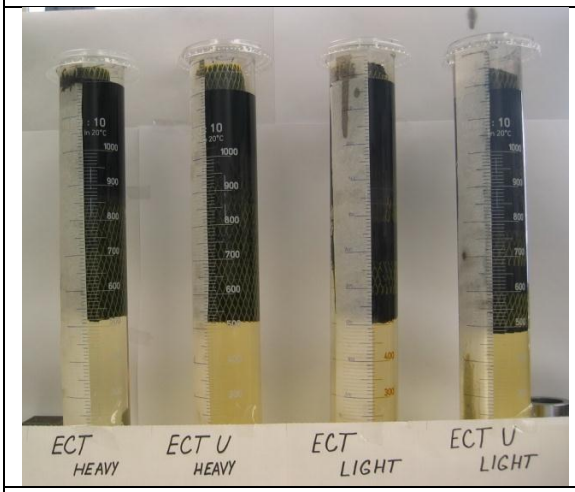
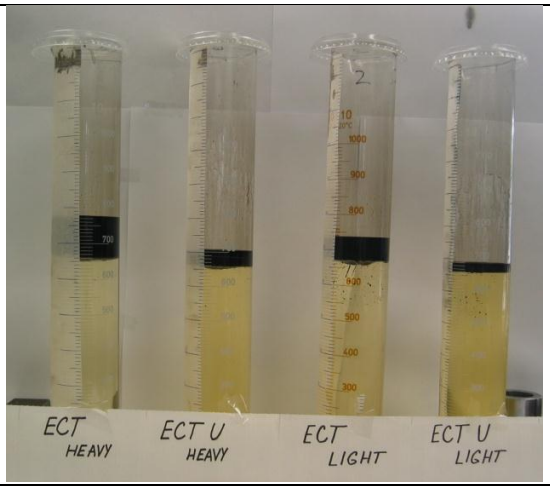
After 23 hour



After take out samples – rest of oil

Process: **Opening:** 750ml water+200ml oil**, Addition:** 10x23ml oil during first 35 minutes
Take out samples from cylinder: after 23 hour

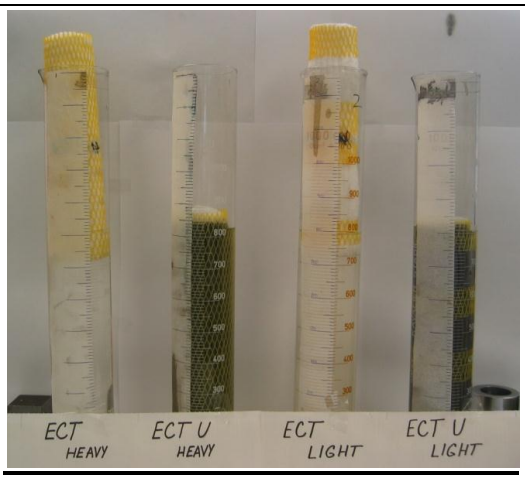
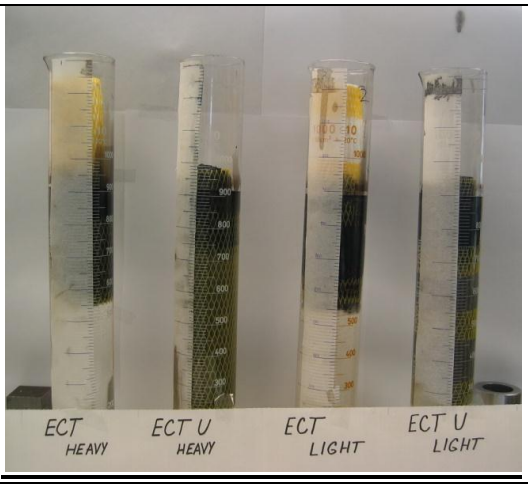
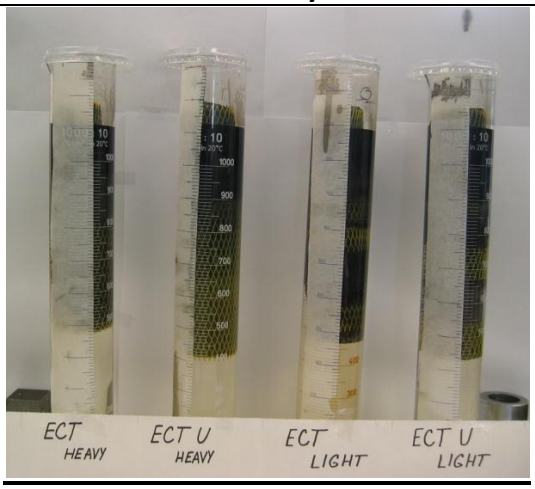
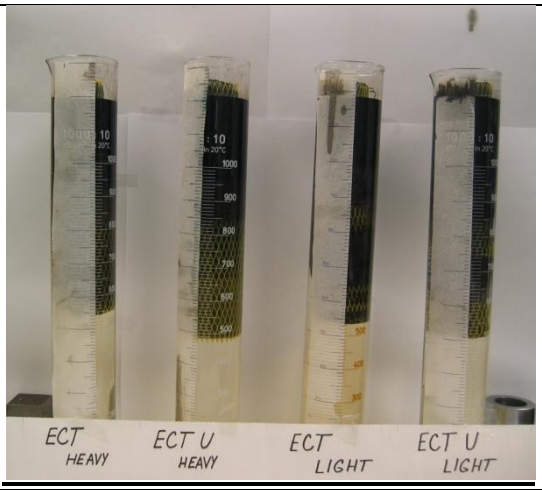
Table 8.32: Oil-water longer test 13 days

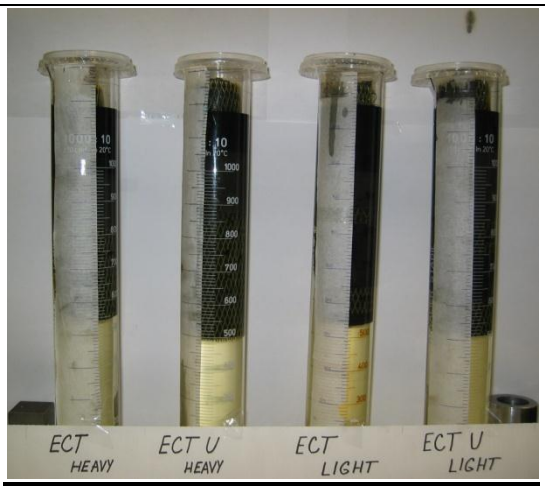
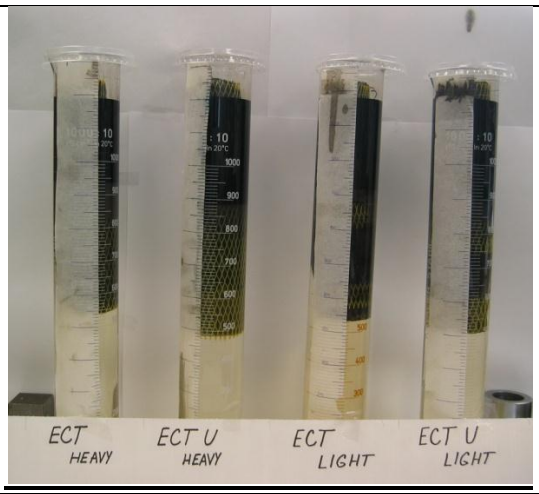
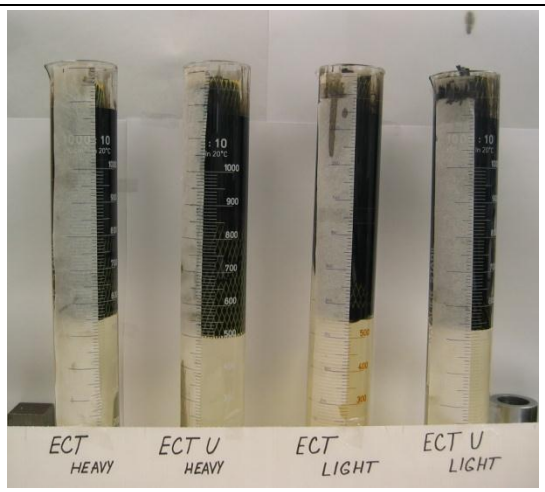
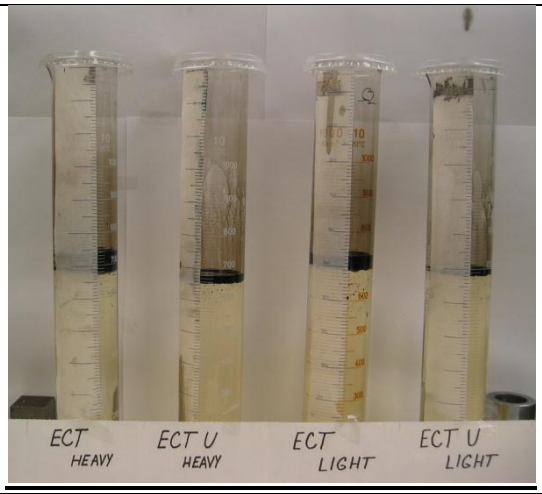
	
First day	**Second day (24 hour)**
	
Third day (48 hour) – After first addition 5x23ml	**Fifth day (120 hour) – after second addition 5x23ml**
	
Thirteenth day (312 hour) – after moving	**After take out samples - rest of oil**

sample	

Process: **Opening:** 750ml water+200ml oil**, Addition:** after 2 and 3 days addition 5x23ml oil
Moving samples in cylinder: 5 min after 12 days, **Take out samples** after 13 days.

Table 8.33: Start water-oil long test 7 days

	
Start of measurement only with water- first day	**Second day (24 hour)- After first addition 5x23ml**
	
Second day (27 hour)– after second addition 5x23ml	**Third day (47 hour) – after third addition 5x20ml**

	
Fourth day (71 hour)- After fourth addition 5x20ml	**Fifth day (97 hour) –before moving sample**
	
Fifth day (97 hour)- after moving of sample	**After take out of sample - rest of oil**

Process: Opening: 750ml water**, Addition:** after 24 and 27 hour 5x23ml, after 47 and 71 hour 5x20ml
Moving samples in cylinder: 5 min after 4 days, **Take out samples:** after 7 days